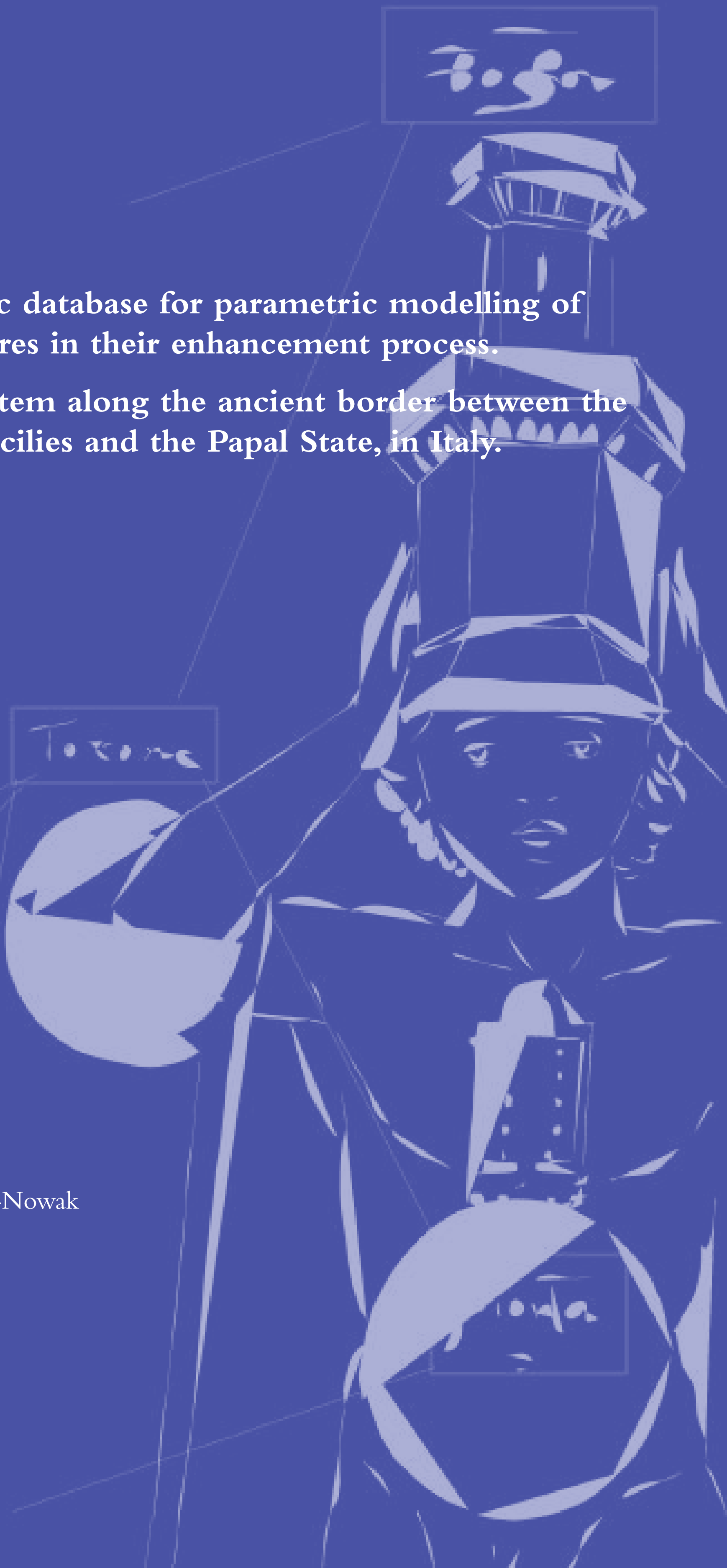
Ontology-based semantic database for parametric modelling of complex architectures in their enhancement process.

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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Scientific Aknowledgments

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Although not straightforward, this doctoral journey was filled with unexpected challenges and detours. These experiences ultimately strengthened this research and significantly contributed to my personal growth.

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.

Abstract

Niniejsza praca doktorska, zatytułowana „Semantyczna baza danych oparta na ontologii do parametrycznego modelowania złożonych architektur w procesie ich konserwacji: Przykład systemu fortyfikacji wzdłuż dawnej granicy między Królestwem Obojga Sycylii a Państwem Kościelnym we Włoszech”, proponuje kompleksową metodologię cyfrowej dokumentacji, analizy i waloryzacji architektury obronnej. Badania koncentrują się na twierdzach położonych wzdłuż historycznej granicy między Królestwem Obojga Sycylii a Państwem Kościelnym, regionie o bogatym dziedzictwie militarnym, ale cierpiącym z powodu braku kompleksowej dokumentacji historycznej. Poprzez integrację narzędzi cyfrowych, takich jak Scan-to-BIM, GIS oraz semantyczne bazy danych oparte na ontologii, praca dąży do stworzenia operacyjnych ram zarówno dla badań naukowych, jak i praktycznych działań konserwatorskich.

Problem stabilnej obrony pojawił się wraz z pierwszymi osiadłymi społecznościami ludzkimi, podyktowany koniecznością ochrony zasad współżycia grupy społecznej przed wrogimi czynnikami zewnętrznymi, zarówno naturalnymi, jak i ludzkimi. Z tego powodu sztuka obrony jest tak stara jak ludzkość i ewoluowała równolegle z postępem ludzkiej wiedzy. Wczesne fortyfikacje opierały się na naturalnych cechach geograficznych jako formach obrony, ale w miarę rozwoju technik ofensywnych konieczne stały się sztuczne zabezpieczenia. Architektura militarna obraca się więc wokół relacji między elementami budowlanymi, równoważąc ich wartości obronne i ofensywne. W historii zamknięcie – fizyczna bariera, taka jak mury, wieże czy fosy – pozostało najbardziej widocznym przejawem potrzeb obronnych. Ewolucja technik fortyfikacyjnych, szczególnie w związku z pojawieniem się artylerii i broni palnej w XV i XVI wieku, głęboko przekształciła te struktury obronne, czego przykładem jest przejście od pionowej „obrony nurkowej” do poziomej „obrony rykoszetowej”, zwłaszcza widocznej w twierdzach bastionowych. To oznaczało fazę przejściową w kierunku nowoczesnej architektury militarnej, zakorzenionej w starożytnych zasadach, ale szybko ewoluującej z powodu nowych technologii.

Pierwsza część pracy ustanawia teoretyczne i naukowe podstawy poprzez przegląd literatury na temat włoskich fortyfikacji. Bada, jak sztuka obrony ewoluowała w odpowiedzi na postępy technologiczne, w szczególności artylerię, oraz jak architekci wojskowi, tacy jak Francesco di Giorgio Martini, przyczynili się do tej transformacji. Badanie porusza również kwestie terminologii architektury militarnej we współczesnych badaniach, zwracając uwagę na złożoność i ewolucję takich terminów jak twierdza, zamek, cytadela i bastion, które często były używane zamiennie, ale odnosiły się do różnych elementów strukturalnych lub celów obronnych.

W kontekście problemu naukowego, praca formułuje kluczowe pytania badawcze dotyczące zachowania i dokumentacji fortyfikacji w przypadku braku odpowiednich zapisów historycznych. Hipotezy badawcze sugerują, że podejście interdyscyplinarne, łączące badania archiwalne, cyfrowe pomiary oraz ustrukturyzowane ontologie, może zrekompensować braki w danych historycznych, oferując bardziej kompleksowe zrozumienie tych obiektów. Celem jest opracowanie uniwersalnej metodologii, która mogłaby być zastosowana w innych regionach i okresach historycznych, zwiększając zarówno zaangażowanie akademickie, jak i publiczne w dziedzictwo fortyfikacyjne.

Główna część pracy skupia się na zastosowaniu procedury opartej na semantycznej bazie danych, nazwanej FORTdigiTALE, która integruje różne formy danych – historyczne, geograficzne i architektoniczne – w zjednoczony model parametryczny. Procedura rozpoczyna się od pozyskiwania danych, wykorzystując techniki fotogrametrii i Structure-from-Motion (SfM) do tworzenia dokładnych modeli 3D fortyfikacji. Te cyfrowe modele są następnie włączane do modelu Heritage Building Information Model (HBIM), co pozwala na szczegółową reprezentację elementów architektonicznych.

Wykorzystanie GIS dodatkowo wzmacnia zrozumienie terytorialne tych struktur, ilustrując ich strategiczne położenie oraz wizualne połączenia w krajobrazie.

Znaczącym wkładem badania jest eksploracja, w jaki sposób analiza ontologiczna może być zastosowana w badaniach fortyfikacji. Poprzez budowę semantycznej bazy danych praca systematycznie organizuje zróżnicowane zestawy danych w spójną strukturę, która wzbogaca zarówno wiedzę naukową, jak i praktyczne wysiłki konserwatorskie. Metodologia ta jest testowana na szczegółowych studiach przypadków pięciu fortyfikacji w południowym Lacjum: San Casto w Sora, Zamek w Vicalvi, Zamek w Alvito, Rocca Janula w Cassino i Zamek Andegaweński w Gaeta. Dla każdego z tych obiektów praca dostarcza dogłębnej analizy historycznej, uzupełnionej katalogowaniem GIS i modelowaniem fotogrametrycznym, co prowadzi do stworzenia ontologicznych modeli opartych na HBIM. Te studia przypadków służą zarówno jako demonstracja metodologii, jak i jako wkład w szersze zrozumienie dziedzictwa fortyfikacyjnego regionu.

Szczegółowe studia przypadków rzucają również światło na złożone czynniki historyczne, geograficzne i polityczne, które kształtowały system fortyfikacji w południowym Lacjum. Praca analizuje wpływ kluczowych postaci historycznych i wydarzeń, takich jak programy fortyfikacyjne Fryderyka II oraz reorganizacja zamków przez Andegawenów, na rozwój architektury obronnej regionu.

Szerokie implikacje badania są omówione w rozdziałach końcowych, gdzie praca rozważa potencjał zastosowania tej metodologii w innych kontekstach, zarówno geograficznych, jak i czasowych. Procedura FORTdigiTALE oferuje skalowalny i elastyczny framework, który może wspierać nie tylko badania akademickie, ale także działania na rzecz popularyzacji, przekształcając modele cyfrowe w dostępne zasoby edukacyjne i turystyczne. Praca opowiada się za bardziej inkluzyjnym podejściem do ochrony dziedzictwa, które integruje zarówno badania naukowe, jak i zaangażowanie społeczności.

Podsumowując, niniejsza praca wnosi wkład w dziedziny cyfrowej ochrony dziedzictwa i badań nad architekturą fortyfikacyjną poprzez opracowanie innowacyjnej metodologii opartej na ontologii do dokumentowania i analizy fortyfikacji. Przełamuje ona lukę między dokumentacją historyczną a nowoczesnymi technikami cyfrowymi, dostarczając cennego narzędzia zarówno dla badaczy, jak i praktyków. Model operacyjny stworzony w ramach tych badań ma potencjał wzmocnienia procesów decyzyjnych dotyczących działań konserwatorskich i waloryzacyjnych, zapewniając, że te historyczne struktury zostaną zachowane dla przyszłych pokoleń.

“Possiamo comprendere l'essenziale solo partendo dai particolari, questa è l'esperienza che ho tratto sia dai libri che dalla vita. Bisogna conoscere tutti i particolari, perché non possiamo sapere quale sarà importante in seguito, quali parole metteranno in luce qualcosa.”

Sándor Márai, Le braci

Bonifacio Bembo (1420-1480),

The Tower, facsimile of a tarot card from the Visconti-Sforza deck, 1441-47.

I

TOPIC

JUSTIFICATION OF THE THEME

SUBJECT

STRUCTURE OF THE WORK

Introduction

Characteristics of the problematic and subject matter of the work

1. Topic and Justification of the theme

The 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" aims to define a procedure for the ontological analysis of fortresses located along historical borders, through digital technologies, Scan to BIM techniques and 3D information modelling (GIS, HBIM) for creating semantic databases. The procedural model is applied on Italian cases of study and is intended to support the decision-making process for valorising areas with similar characteristics in Europe. The settlements of architectural objects of high historical and symbolic value strongly characterise different geographical areas in various regions of Europe. Among the various reasons for their construction, religious paths and river routes, the most peculiar purpose is the defence, which has created real systems in border areas between states.
Different architectural language: towers, fortresses, defensive structures, and solutions designed specifically for the site, following the orography of the terrain, were always part of a network that connected them. Having ceased their military functions, fortified buildings maintained a strong symbolic

value within the rural and urban landscape [Boscarino, 2001]. Today, castles and towers hold the cultural, urban and landscape identity of the communities in which they are embedded [ICOMOS, 2008], the transformations traceable in the architectural apparatus reflect and bear witness to the historical and political events of the area to which they belong. If, at a fleeting glance, the fortified buildings may appear as punctual elements arbitrarily arranged in the landscape, they constitute a system in which the assets, relating to each other and to the respective contexts, are integrated into a broader and more complex network of cultural heritage made up of resources with historical, artistic and environmental value [Parise, 2023]. The valorisation process can only start from the recognition of the historical and identity value of each asset by the communities in which the assets are located, as well as by the administrations and managing bodies, which must be made aware so that ordinary maintenance operations are carried out [Carbonara, 2000].
Abandonment, underutilisation and the absence of an adequate valorisation project put the preservation and existence of the objects themselves to the test, which is why it is necessary to undertake protection and valorisation actions that originate from the knowledge and recognition of the identity value enclosed within each architectural objects. [Acierno, 2020].
The present research has a focus on this delicate period which starts from late medieval architecture to the very beginning of the modern military architecture bearing the marks of tradition. From the identification and cognitive investigation phases, it has been possible to ascertain how the greatest concentration of defensive structures is located in territories characterised by mighty mountainous reliefs and scattered high ground (inland and on the coast), natural elements used for the foundation of the buildings, simultaneously exploiting the altimetry for territorial control and the orography for the defence system of the slopes of the buildings themselves.

2. The scientific problem, hypothesis and research questions

The preservation and development of heritage at a territorial level, such as the network of fortified structures, necessitates a comprehensive understanding of its historical context. This understanding should encompass not only the military-defensive history and architectural language but also the interplay with the environment, urban context, and the

physical elements that constitute the entire cultural heritage [Villa, 2015].
The study of military architecture is a vast field, and the first step towards its comprehension is a thorough review of the literature. This includes a detailed examination of the evidence presented in treatises. A key aspect that emerges from this literature is the establishment of a relationship between the various parts, aimed at creating a distinct and independent entity.
This knowledge, combined with collecting historical-archival data, flowed into constructing the ontology of fortified architecture on the historical border between the Kingdom of the Two Sicilies and the Papal States, now in neglect. The ontology is preparatory to constructing integrated information models that can raise awareness about the state of the architecture in question, which the present study intends to investigate.

Research assumptions:

- Scarcity of historical documentation:

Given the rarity of historical documentation concerning it, fortified architecture can be conserved and analyzed correctly using interdisciplinary methodologies, from archaeological and architectural ones to 3D modeling and structured ontologies. Accordingly, poor documentation can be compensated for by combining the different techniques that enable efficient levels of understanding the medieval fortification.

- Construction of informative models through structured ontologies:

This, in turn, would serve to build a better realization of knowledge and understanding regarding medieval fortifications. Ontologies are structured representations of information that, while applied to data, can assist in systematically sorting and modeling the fortification data of any kind, hence improving the conservation and scholarly understanding.

- Awareness of neglected fortifications:

Poor state of information on the status of the fortifications, which have been left in neglect; more documentation and public engagement is needed to whip up interest in their preservation. The need for more attention and effort in preserving these historical structures shows the gap between current conditions and awareness at the public/institutional level.

- Methods of fortification studies.

In this way, universal methodology of analysis for the fortified architecture will be developed, one that can also be applied in other regions or periods, while ensuring coherent analytical and conservative interventions. The methodology developed within this thesis examines its broader applicability and adaptability concerning the study of historical fortifications.

- Data used in promotion and education.

Information from historical and digital analysis can be objectively transformed into promotional and educative uses that might improve public participation in cultural heritage through the use of digital facilities. Digital technologies and structured data could help in promoting historical knowledge and engaging the public in heritage conservation through digital storytelling and interactive tools.

Research questions:

How can historical analysis be conducted to conserve fortified architecture? This research aims to provide a roadmap for this, even when the documents, especially from medieval areas, are scarce.

The construction of informative modeling integrated with structured ontology can enhance knowledge about fortifications and in which way? What is the level of awareness regarding the conditions of neglected fortifications?

Moreover, does the presence of two distinct states, the papal and the Kingdom of the two Sicilies, in southern Latium, region chosen for the application of the procedure established in this thesis, give rise to any differentiation? Is the plurality of often autonomous and antagonistic powers found in the facies of the castles, and in what way? How much and in what ways did technologies determine building processes? How much was the building of fortresses conditioned by environmental situations, and how much by political will? Are they arranged along state and lordly defence lines, or do they pursue other interests? What relationship exists between fortresses and urban centres of reference?

Finally, is it possible to develop a universal method to apply it to the study of other objects? How to use the collected data for promotional and educational purposes, according to FORTdigiTALE procedure?

3. Research objectives

The scientific objective of the research is: 1) the testing and construction of parametric information models of the HBIM type based on a complex ontological structure that aims at detailed knowledge, or the essence, of all building components of fortified architecture. 2) Developing the state of scientific knowledge of defense facilities in the study area.

The methodological objective is identifying a simplified procedure, called by the author FORTdigiTALE, for acquiring heterogeneous data, historical-archival, technical-constructive and metric-material, for the informative and digital construction of the fortified architectures chosen as case studies. To this end, SfM (Structure from Motion) surveys and Scan to BIM type procedures are fundamental, as they allow precision volumetric modelling of complex architectures in terms of their morphological conformation and, above all, their location.

The operational objective is to provide an operational tool to facilitate the decision-making process for those working in the field, municipal administrators and technicians in charge of planning re-functionalisation or restoration work on fortified architectures and to improve the understanding of the works for stakeholders and their involvement in investments for the restoration of historic sites.

The objective of promoting the architectural heritage is that the digital models, obtained with the FORTdigiTALE[1] procedure, can be visualised on web platforms, then made accessible and interrogable in open access if aimed at the process of valorisation and tourist knowledge or by subscription for technicians requiring more in-depth knowledge and processing.

4. Subject and scope of the research

The case studies presented are located along the ancient border between the Papal States and the Kingdom of the Two Sicilies. It is important to recall that the first major Italian state formed during the medieval period (11th-12th centuries) was the Kingdom of Sicily (Figg. 1, 2). Although technically a vassal of the Papal States, the Kingdom exhibited imperial ambitions, expanding northward to Montecassino and Abruzzo, southward and southeastward toward present-day

1. The name FORTdigiTALE highlights the narrative aspect of this method, emphasizing not only the technical precision of the digital reconstruction but also the storytelling dimension, where historical and architectural data are woven into a comprehensive and engaging narrative about the fortifications and their evolution. This approach adds value by making the heritage more relatable and understandable to a wider audience, while still providing the depth of information necessary for specialized users.

Fig. 1. Rizzi Zannoni, 1808, Atlas of the Kingdom of Naples, board 5 (detail); Sora is on the north. Biblioteca Nazionale di Firenze.

Fig.2. Rizzi Zannoni, 1808, Atlas of the Kingdom of Naples, (detail); Gaeta gulf is visible in the south. Biblioteca Nazionale di Firenze.

Tunisia and Tripolitania, and eastward to the coast of Albania and the Island of Corfu. It also controlled the three key strategic passages of the central Mediterranean: the Strait of Sicily, the Strait of Messina, and the Otranto Channel. The Kingdom's socio-political structure was marked by the coexistence of an autocratic monarchy and strong feudalism. In Southern Latium, numerous fortifications are found, primarily along the border and the Tyrrhenian coast, known as the Ulysses Riviera, as well as inland. These fortifications, which include castles, fortresses, and watchtowers of various shapes (circular, square, and polygonal), were strategically positioned for both defense and surveillance. Their spatial distribution was strongly influenced by the region's orography and the visual interconnections between them.

Latium presents a fascinating case study with a complex history. The region's name, which had largely fallen out of use by the Classical era, re-emerged during the Middle Ages to describe territories under Papal authority, as well as those of the southern kingdoms. The Liri River, while functioning as a boundary, also acted as a bridge, facilitating exchanges and cultural admixture across the broader territorial landscape. This study reconstructs the defensive structures of the border by identifying both material remains and the cultural exchanges that occurred across these boundaries. Understanding the evolving political and administrative decisions that shaped the region from Roman times to the present is crucial, as these decisions have profoundly influenced the physical landscape. These demarcations—whether separating states, peoples, or fortifications—continue to shape local development and territorial transformations. Territoriality thus plays a symbolic and cognitive role, mediating between the physical landscape and social dynamics. During the Byzantine era, fortified settlements were established in areas deemed administratively and politically strategic. By the Lombard period, territoriality was further defined through the creation of counties. Norman counties, established later, were similarly delineated by clear boundaries[3] [Cuozzo 2006, pp. 287-304] Observing the territory and the needs of its communities allows for an analysis of power dynamics, social structures, and the evolving landscape.

The castle of San Casto in Sora, located in Southern Lazio, served as the centerpiece of a defensive system that included satellite fortresses such as those at Balsorano, Roccavivi, and Isola del Liri, as well as, to a lesser extent, Vicalvi and Alvito.

Unfortunately, many of these fortifications have been abandoned, resulting in significant gaps in our historical and architectural knowledge. These fortresses are part of a broader geopolitical phenomenon known as "incastellamento"[2], which developed between the 9th and 12th centuries. Pierre Toubert codified this term in his seminal work "Les Structures du Latium médiéval" [Toubert, 1973], identifying three key factors that transformed the agrarian landscape of the Liri Valley: population concentration in secure and economically favorable areas, the fortification of cities, and the formation of territorium castri around these fortified sites. The complexity of this process is further illustrated by divergent theories, such as those of Lauwers, who emphasized the pivotal role of churches and abbeys in social and spatial development [Lauwers, 2012]. Many of the region's fortresses are located on orographically complex sites, often at the summit of hills. As Francesco di Giorgio Martini stated in his Treatise on Civil and Military Architecture (c. 1481-1486), "the best defense of a fortress is not its walls or engineering, but the high, impassable mountains."

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2. The phenomenon of incastellamento, which flourished from the VIII and IX centuries, represents a crucial moment in the transformation of the landscape and social structure of medieval Europe. Fortifications, strategically located, contributed not only to military protection but also to the reorganization of local communities and economies. Various scholars have analyzed this phenomenon from different perspectives, enriching the debate with relevant and multidisciplinary contributions. Pierre Toubert, in his study "Les structures du Latium médiéval" (1973), highlights the close link between the feudal power system and incastellamento, describing how castles played a central role in the construction and consolidation of seigneurial power. Toubert emphasizes how, in the context of central Italy, fortifications became the core of a meticulous control of agricultural resources and communication routes, essential elements for maintaining local authority. Philippe Lauwers, in his essay "L'incastellamento: Défense et société en Europe médiévale" (2001), delves into the social aspect of the phenomenon, highlighting how castles were not only defensive tools but also centers of aggregation and development for surrounding rural communities. Lauwers also underscores how incastellamento reshaped power relations, transforming social dynamics through the creation of protection networks and collaboration between lords and local populations. From an archaeological perspective, Riccardo Francovich, in his work

"Castelli e villaggi nell'Italia medievale" (1994), focuses on the analysis of the material structures related to incastellamento. Through excavations and archaeological studies, Francovich demonstrated that incastellamento involved a profound reorganization of the territory, influencing settlement distribution, production models, and the economic organization of the regions studied, particularly in Tuscany. His interdisciplinary approach, which combines written sources with archaeological data, has opened new perspectives in the study of territorial management during the Middle Ages. Subsequent academic studies, such as those by Chris Wickham in his "Framing the Early Middle Ages" (2005), offer a broader view of the phenomenon, connecting it to economic transformations on a continental scale and a wider redefinition of political power in Western Europe. Wickham stresses that incastellamento was not an isolated process but part of a larger system of changes that influenced social, economic, and political structures during the transition from Antiquity to the Middle Ages.

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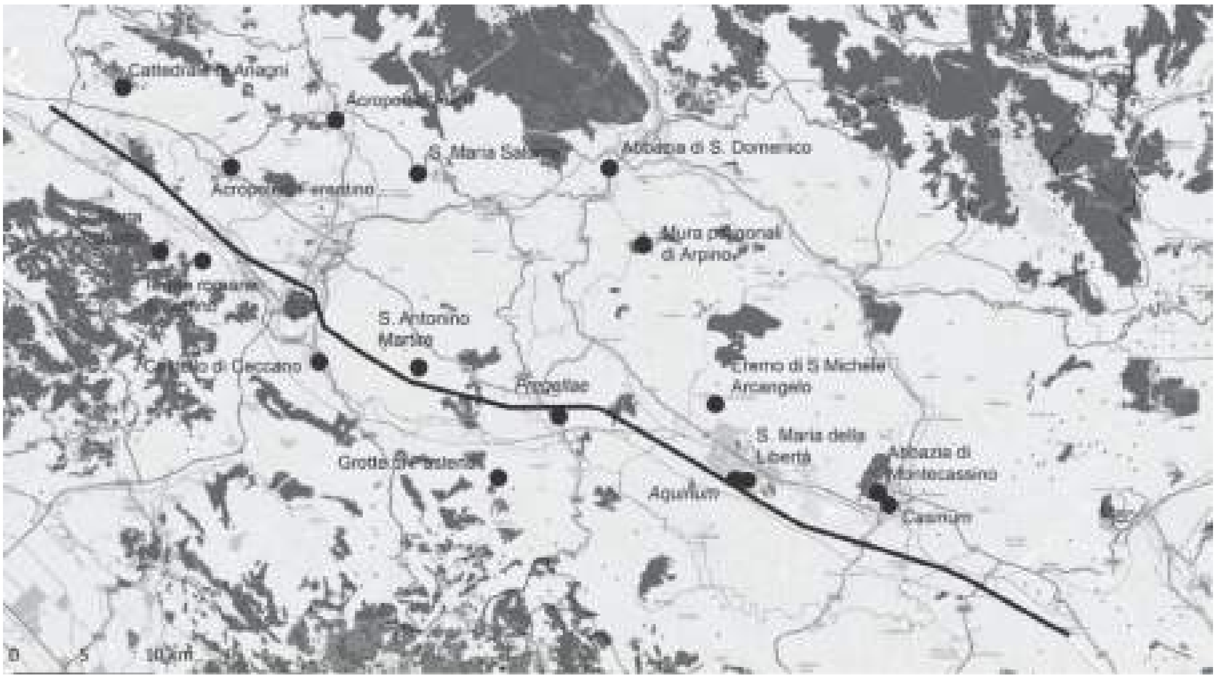

Fig.3.The Liri Valley, crossed by the Via Latina artery, part of Latium Adiectum. (Elaboration by the author)

4.1. Area and time scope of the research

This research focuses on three historically and strategically significant regions of Southern Lazio: the Liri Valley, the Comino Valley, and the Gaeta Peninsula. These areas, each with its own distinct geographical features, have played pivotal roles in the military, cultural, and economic history of central and southern Italy, serving as critical crossroads of power and influence from ancient times through the modern era.

The Liri Valley, (Fig.3), framed by the Volsci pre-Apennine range and the Ernici-Simbruini mountains, has been a vital communication artery between Lazio and Campania since prehistoric times. Its strategic importance was reinforced through Roman colonization, as it became part of crucial transportation and defense networks. Over the centuries, the valley has been a frontier zone, witnessing continuous territorial contestation, from the Roman-Samnite conflicts to its role in World War II, where its geography again influenced the course of military operations.

The Comino Valley, situated near the Abruzzo Apennines and historically linked to the Terra di Lavoro, offers a compelling example of a medieval landscape dominated by a network of castles. The valley's association with the powerful Benedictine monasteries and feudal lords left a rich legacy of religious and architectural heritage. Its unique positioning at the borderlands of several important medieval polities underscores its historical significance as a contested and influential region.

The Gaeta Peninsula, jutting into the Tyrrhenian Sea, is a remarkable natural stronghold that has served as both a military and maritime hub. Its strategic importance, evident since Roman times, peaked in the medieval and Renaissance periods when it became one of the most fortified locations in the Mediterranean. Gaeta's role in pivotal historical events, including the Norman conquest and the Risorgimento, underscores its status as a key stronghold, safeguarding central Italy's coastline and sea routes.

Together, these regions form a complex and interconnected tapestry that has shaped the geopolitical and cultural landscape of Southern Lazio. The Liri Valley and Comino Valley served as essential land corridors linking central and southern Italy, while the Gaeta Peninsula controlled critical maritime routes. These regions not only witnessed ancient conflicts between Romans, Samnites, and Oscans but also played significant roles in medieval power struggles and modern Italian history, reflecting their enduring importance as strategic crosspoints of culture, trade, and military operations. This chapter explores their multifaceted histories, emphasizing their continuous influence on the broader historical developments of the Italian peninsula

Liri Valley

The Liri Valley, named after the river that flows through it, is nestled between the Volsci pre-Apennine range and the Ernici-Simbruini mountains. Since prehistoric times, it has served as the main communication route between Lazio and Campania. After its conquest by Rome and the establishment of several colonies along the river's course, and traversed by the Via Latina, the valley became part of Latium Adiectum and later, under the Empire, of Regio I Latium et Campania. With the fall of the Roman Empire, it became a border zone between Byzantine territories and various kingdoms and duchies of Southern Italy. Its role as a strategic link between southern and central Italy was again evident during World War II, when Allied forces advancing from Campania used it to

their advantage. The Liri Valley, located in Southern Lazio within the province of Frosinone, spans the territory through which the Liri River flows (as does the Roveto Valley in Abruzzo, which is also part of this region). The primary urban center in the area is Sora.
The Liri Valley corresponds to what is known as the Lower Latin Valley. More specifically, following the course of the Liri River, the valley is often referred to as the Middle Liri Valley, since it encompasses only the mid-level stretch of the river. The terrain is mostly hilly, and the valley itself begins around the town of Sora, an ancient settlement at the border of Lazio and Abruzzo, near the central Apennine mountains.
Before the Roman conquest and Latin colonization, the valley was inhabited by the Volsci, an Indo-European people who, unlike the Latins, were part of the Oscan-Umbrian linguistic family, making them culturally closer to other Italic populations of the Apennine regions. To the south lay the territory of the Samnites, also of Oscan-Umbrian origin. Following Rome's expansion into Lazio, the Liri River initially became the boundary between Roman territory and the land of the Samnites (Samnitium ager). Important centers such as Fregellae, Sora, and Arpino developed in the valley. Fregellae and Sora, both Latin colonies, were populated by thousands of Roman and Latin settlers. The founding of the Latin colony at Fregellae within Samnite territory triggered the Second Samnite War.
After Roman expansion, the area was incorporated into Latium Adiectum and, during the imperial period, into Regio I Latium et Campania. With the fall of the Roman Empire, and after the Gothic and Byzantine periods, the valley became a border region between the Byzantine (later Papal) territories and the southern duchies and kingdoms. The main local lordships, although orbiting the Kingdom of Naples, were the County (later Duchy) of Sora and the Terra di San Benedetto, the latter being a feudal domain of the Abbey of Montecassino. In 1870, the two banks of the Liri River were reunited, albeit within different provinces. In 1927, with the establishment of the province of Frosinone, the towns of the Alta Terra di Lavoro, east of the Liri and north of the Garigliano River, were re-integrated into Lazio.

Fig.4. Comino Valley, the municipalities are visible in blue. (Elaboration by the author)

Comino Valley

The Comino Valley (Fig.4) is located in the province of Frosinone, historically part of the Alta Terra di Lavoro region, near the Abruzzo Apennines and the Abruzzo, Lazio, and

Molise National Park. The valley largely corresponds to the upper watershed of the Melfa River, which carves its way through the limestone of Monte Cairo and eventually flows into the Liri Valley. According to tradition, the valley's name is derived from the ancient city of Cominium, which, as recounted by Titus Livy and Dionysius of Halicarnassus, was destroyed in 293 BC during the Third Samnite War. While no Roman-era inscriptions mentioning the city have been found, by the Middle Ages, the entire valley was already referred to as Comino in documents, and this name appears in the works of Flavio Biondo and Leandro Alberti. The name survived through the centuries and is reflected in modern place names such as San Donato Val di Comino, the Valle di Comino Mountain Community, and the Union of Municipalities of Val di Comino. In the Middle Ages, the valley was dominated by a network of castles, many of which correspond to the present-day towns (Atina, Agnone, now known as Villa Latina, San Biagio Saracinisco, Picinisco, Settefrati, San Donato Val di Comino, Gallinaro, Alvito, Vicalvi, Campoli Appennino, Casalvieri, and Casalattico). These settlements were part of the Lombard Duchy of Spoleto, the Principality of Capua, and later the County of Aquino and the County of Marsi, eventually joining the Norman Kingdom as an autonomous county, and later duchy, known as the State of Alvito. The most prominent families to rule over the valley were the d'Aquino, Cantelmo, Borgia, and later the Gallio.
During the early Middle Ages, the valley was heavily influenced by the Benedictine monasteries of Montecassino and San Vincenzo al Volturno, shaping its religious and cultural identity. The medieval period left behind a rich heritage of churches, castles, towers, and walls, with notable examples in the castles of Alvito and Vicalvi, as well as the Cantelmo Palace in Atina. The Comino Valley followed the fate of the Kingdom of Naples and later the Kingdom of the Two Sicilies. After Italy's unification, it became a hotspot of anti-unification resistance, particularly during the brigandage period, which had roots in the counter-revolutionary guerrilla warfare against the French Jacobin invasion. It remained part of the province of Caserta and was incorporated into the Terra di Lavoro until 1927, when the district of Sora was added to the newly formed province of Frosinone in Lazio.
Besides the traditional Comino castles, which form a circle along the edge of the valley, the Comino Valley Mountain Community also includes the towns of Belmonte Castello, Posta Fibreno, Campoli Appennino, Pescosolido, and Fontechiari, along with Vallerotonda, Acquafondata, and

Viticuso, all historically connected to Montecassino and part of the Terra Sancti Benedicti.

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Gaeta Peninsula

The Gaeta Peninsula is a striking and historically significant area of Southern Lazio, projecting into the Tyrrhenian Sea and forming a natural strategic point between the Papal States and the Kingdom of Naples. The city of Gaeta, located on the promontory, was a key stronghold and port throughout its history, particularly in the medieval period and the Renaissance.

Gaeta's historical importance is evident from its role as a military fortress and trading hub. During the Roman Empire, it was a popular location for patrician villas and became renowned for its natural beauty. The strategic importance of Gaeta increased during the Middle Ages, especially as it became a significant naval base in the wars between the Byzantines, the Lombards, and the Saracens. In the 9th century, Gaeta was established as an independent duchy and played a crucial role in the defense of central Italy against invasions from the sea.

During the Norman Conquest, Gaeta was incorporated into the Kingdom of Sicily and later the Kingdom of Naples, and it remained a key fortification. The Aragonese and Bourbon dynasties fortified the peninsula, especially during the 15th and 16th centuries, turning Gaeta into one of the most formidable strongholds in the Mediterranean.

Gaeta also has a notable place in Risorgimento history as the location of the last stand of King Francis II of the Kingdom of the Two Sicilies. After the fall of Naples, Gaeta became the final refuge of the Bourbon monarchy during the siege of 1860-61, marking the end of the Kingdom of the Two Sicilies and its incorporation into the newly unified Kingdom of Italy.

Today, the Gaeta Peninsula is known for its rich historical legacy and its strategic importance during key moments in

Italy's history. Its well-preserved fortresses, such as the Castello Angioino-Aragonese, serve as reminders of its defensive past. The area's unique geography, with its promontories, cliffs, and secluded coves, made it an ideal location for both military and commercial activities throughout the centuries.
In addition to its military significance, the peninsula is also famous for its religious and cultural history, housing important landmarks such as the Sanctuary of Montagna Spaccata and the Cathedral of Gaeta, which showcase the region's deep-rooted ties to both Christianity and maritime culture.

The Liri Valley, Comino Valley, and Gaeta Peninsula together represent a rich tapestry of historical, strategic, and cultural significance in Southern Lazio. While the valleys served as critical land routes linking central and southern Italy, Gaeta stood as a maritime fortress controlling key naval passages in the Tyrrhenian Sea. These regions not only bore witness to the ancient struggles between Romans, Samnites, and Oscans but also played pivotal roles in medieval and modern Italian history, from the Norman conquests to the Risorgimento and Italy's unification. Each area's complex and multifaceted history reflects the enduring geopolitical importance of Southern Lazio as a crossroads of cultures, armies, and trade routes.

5. Author's research methodology

The research methodology is designed to thoroughly investigate the historical, architectural, and geopolitical aspects of the fortifications in Southern Lazio. The methodology is structured to combine both qualitative and quantitative approaches, integrating archival research, digital survey techniques, and a comprehensive analysis of territorial dynamics. Special emphasis is placed on the use of the FORTdigiTALE procedure, which enables precise digital reconstructions of architectural heritage, facilitating both scholarly analysis and broader public engagement. By adopting a multidisciplinary approach, this methodology aims to provide a deeper understanding of the fortifications' historical evolution, their strategic roles, and their influence on the surroundings.

5.1. Sequence of research proceedings

The research methodology is divided into two main stages: a general study and a detailed study, regarding a selection of cases of study for an in-depth analysis based on predefined criteria. The research design adopts a comprehensive approach to analyse fortified architecture.

The two primary stages of the methodology serve distinct but complementary purposes. These stages are designed to establish both a broad understanding and a focused analysis of key fortifications. The research incorporates advanced digital tools, including photogrammetry and GIS, to enhance both the documentation and the interpretation of architectural data, ensuring a precise and multi-dimensional examination of the subject matter. This phased approach allows for a broad initial survey followed by an intensive, detailed analysis of specific fortifications. This is justified by the need for both breadth and depth in historical research. The section "General study" provides the necessary historical and geographical Italian context, while the "Detailed study" allows for an intensive examination of selected examples in Southern Latium, highlighting specific architectural and geopolitical dynamics.

The first stage, referred to as the general study, serves to build a foundational understanding of the fortified structures in the region by exploring the broader historical context and identifying significant themes in military architecture. This stage involves a comprehensive review of critical historical sources and bibliographical documentation. The second stage focuses on the in-depth analysis of selected fortifications through case studies. The selection process for these case studies is based on specific criteria that highlight the architectural, strategic, and historical importance of each site.

The first stage of this research involves a comprehensive exploration of the evolution of fortified architecture in Italy. This stage draws on a well-established bibliography, focusing on historical sources that detail the development of military fortifications in Italy, as well as treatises on military architecture. In particular, attention is given to the works of Francesco di Giorgio, whose treatises incorporate Vitruvian precepts and offer insight on the preexistent fortified structure and into the principles that shaped Renaissance military architecture. The general study seeks to explore the fortification phenomenon in Italy through both written sources and archival materials, which provide valuable awareness into how these structures were perceived and utilized across different time periods. Fortresses and castles have been seen through various lenses over the last two centuries, their function evolving based on the historical moment and the social context in which they existed. The frequent presence of isolated castles, fortified villages, or city walls, still visible across the Italian landscape, reflects their dual role as components of both civil and military history. These structures are not merely remnants of military architecture but are deeply tied to the development of art, science, and culture, thus bridging the gap between military and civil histories, as argued by scholars like P. Marconi [1978].

This general study establishes the historical and thematic context for the fortifications, exploring their architectural and cultural significance over time. By the end of this stage, the research builds a solid knowledge base from which specific fortifications can be selected for further analysis. The thorough analysis of written sources, such as military architecture treatises and specialized dictionaries, while dating from a period later than that of the selected case studies, has been pivotal in the semantic categorization of fortification components and the subsequent development of the associated ontology. A significant number of these treatises, notably that of Francesco di Giorgio, commence with the study of earlier constructions to inform their modernization. In much the same way, the fortifications under examination in this study—despite their early medieval origins—have been subject to numerous modifications throughout their history.

The second stage, the detailed study, shifts focus from the broader context to a closer examination of selected fortifications. These examples are chosen based on several key criteria that highlight their geopolitical importance, architectural uniqueness, historical documentation, and their relationship to the surrounding landscape. The selected fortifications must have played a significant role in territorial defense and must exhibit distinct architectural features that reflect innovations in military design. Additionally, these sites must be sufficiently preserved to allow for detailed analysis through both historical records and modern surveying techniques. A prime example of a fortification chosen for detailed study is San Casto Castle in Sora, Lazio, which was a central point in the defensive system of the region. Perched on the historically strategic Monte San Casto, the castle controlled a crucial passage between the Papal State and the Kingdom of the Two Sicilies. The spatial layout of San Casto and its satellite fortresses, such as Balsorano and Roccavivi, is closely tied to the orographic features of the landscape, creating a sophisticated defense network that was essential for the control of the Liri Valley. The case study of San Casto, along with other fortifications in the region, serves as an example of how geography and architecture intertwine to form a cohesive military strategy. Once these case studies are identified, the detailed study involves several phases of investigation. Direct architectural surveys are conducted using advanced digital tools such as digital aerial photogrammetry and Structure from Motion (SfM) technology, both of which allow for the precise documentation of the current state of the fortifications. These technologies generate highly accurate 3D models and digital ortho-images that enable detailed analysis of the fortifications' structure and geometry. Additionally, GIS (Geographic Information Systems) is used to map the spatial relationships between fortifications and their surrounding landscapes, offering insight into how these structures were strategically placed in relation to the terrain.

The data collection process for the case studies is multifaceted, combining traditional archival research with modern digital surveying techniques. Historical documents, including military records, architectural plans, and maps, are obtained from archives such as the Vatican Archives and Archivio di Stato di Napoli. Alongside archival research, on-site surveys are conducted using UAV (Unmanned Aerial Vehicle) photogrammetry and laser scanning technologies. These tools enable the creation of detailed 3D models of the fortifications, capturing not only their architectural features but also their relationship to the surrounding landscape. For example, the UAV-based aerial surveys provide a comprehensive view of the fortifications' topography, allowing for a better understanding of how the orographic features of the region influenced the design and functionality of the fortresses. The collected data is then analyzed using various methods. The 3D models generated through SfM are used to study the geometric deformations of the fortifications, identifying structural weaknesses and areas of potential restoration. GIS mapping allows for the spatial analysis of the fortifications' locations, helping to visualize their strategic importance and their interconnectedness within the broader defensive network. Furthermore, these digital tools facilitate the comparison of historical and current states of the fortifications, offering insights into their preservation and deterioration over time. The integration of advanced digital tools such as digital photogrammetry and GIS mapping plays a critical role in the detailed study of the fortifications. These tools provide several advantages, particularly in terms of accuracy, efficiency, and the ability to document structures located in difficult or inaccessible areas. For example, the use of UAVs allows for the surveying of fortifications situated on remote or mountainous terrain, offering a level of detail and precision that would be difficult to achieve with traditional surveying methods.

The digital survey techniques employed in this research also enable a more nuanced understanding of the relationship between the fortifications and their landscapes. By creating detailed 3D models of both the architectural structures and the surrounding terrain, the research can explore how the natural features of the region shaped the design and placement of the fortifications. This relationship between architecture and landscape is crucial for understanding the strategic importance of the fortifications in controlling key territories along the historical border.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 by the modeling technologies that iconically reproduce real objects, restoring a coherent perception of the raison d'être of the artifact. 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. In fact, SfM technology returns 3D models and digital ortho-images of objects with high precision by processing point clouds and recorded digital images. In particular, short-range digital photogrammetry offers crucial opportunities, such as automatic orientation and measurement procedures, 3D vector data generation, digital ortho-imaging, 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 general study provides a comprehensive overview of the historical, architectural, and cultural significance of fortifications, establishing the necessary context for further analysis. This broad perspective is then narrowed in the detailed study, which focuses on specific fortifications chosen for their historical and architectural relevance. By employing advanced digital tools in the detailed study, the research is able to move beyond traditional methods of historical analysis, offering new insights into the fortifications' construction, preservation, and relationship with the surrounding landscape.Despite the advantages of digital technologies, certain limitations exist within the methodology. Incomplete archival records or restricted access to specific sites may limit the scope of the analysis. Additionally, the use of older historical maps presents challenges in terms of accuracy, particularly when attempting to overlay these maps with modern GIS data. These limitations are mitigated by cross-referencing multiple sources and using modern technologies to fill in gaps where possible. The methodology developed for this research combines historical-critical analysis with modern digital tools to create a comprehensive framework for studying fortified architecture. Through this approach, the research contributes to both the scholarly understanding of fortified architecture and the ongoing efforts to preserve and enhance these cultural heritage sites (Figg. 5,6).

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5.2 Research techniques:

Structure from Motion (SfM): A photogrammetric technique employed in computer vision and remote sensing to reconstruct 3D structures from 2D image sequences. This process captures overlapping images of an object or scene from various angles and uses algorithms to estimate the three-dimensional coordinates of points, as well as the positions and orientations of the cameras. SfM is widely used in disciplines such as archaeology, architecture, and geology for producing highly detailed 3D reconstructions.

Digital Aerial Photogrammetry: A technique for obtaining precise measurements and creating maps or 3D models from aerial imagery using digital methods. Images are captured from aircraft or drones equipped with digital cameras, and specialized software processes these images to extract spatial information. This approach is commonly applied in areas like topographic mapping, environmental monitoring, urban planning, and agriculture, allowing for detailed analysis and visualization of landscapes and structures.

Scan to BIM (Building Information Modeling): A process that captures the physical characteristics of buildings or infrastructure using 3D laser scanning or other reality capture technologies and converts this data into a detailed digital 3D model. These models can be used for renovation, maintenance, and facility management. The 3D scans provide highly accurate geometric data, which is then processed and integrated into a BIM system, delivering a precise representation of the building's structure and systems.

Tools used in the research:

Photographic camera	Canon EOS 850D, EF-S18-55mm f/4-5.6 IS STM
Drone	DJI Mini 2
3D HBIM modeling software	Autodesk Revit
Point cloud management software	Agisoft Metashape, Autodesk ReCap; Cloud Compare

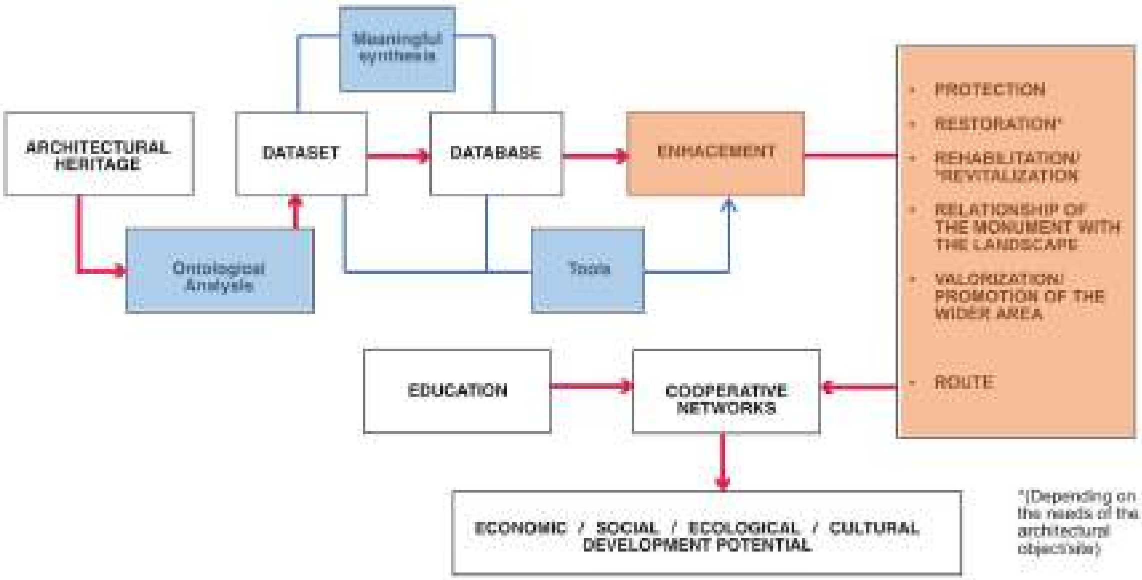


Fig. 5. Workflow steps for the enhancement of the neglected architectural heritage. (Author's elaboration)

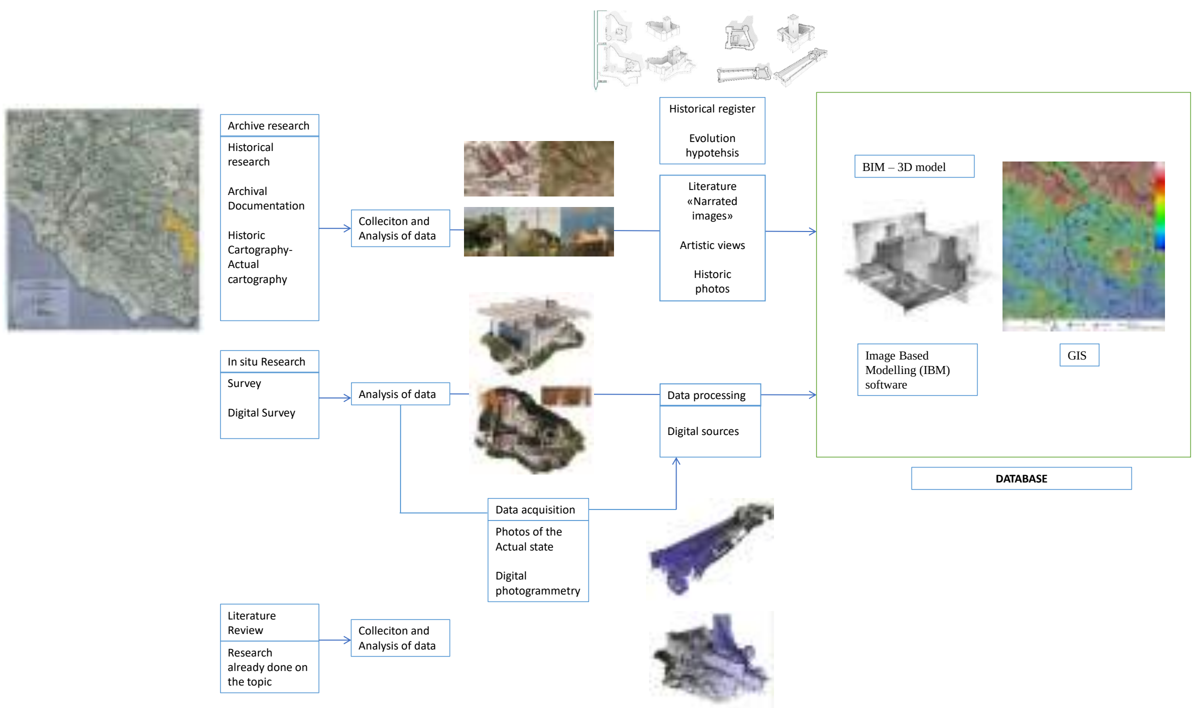
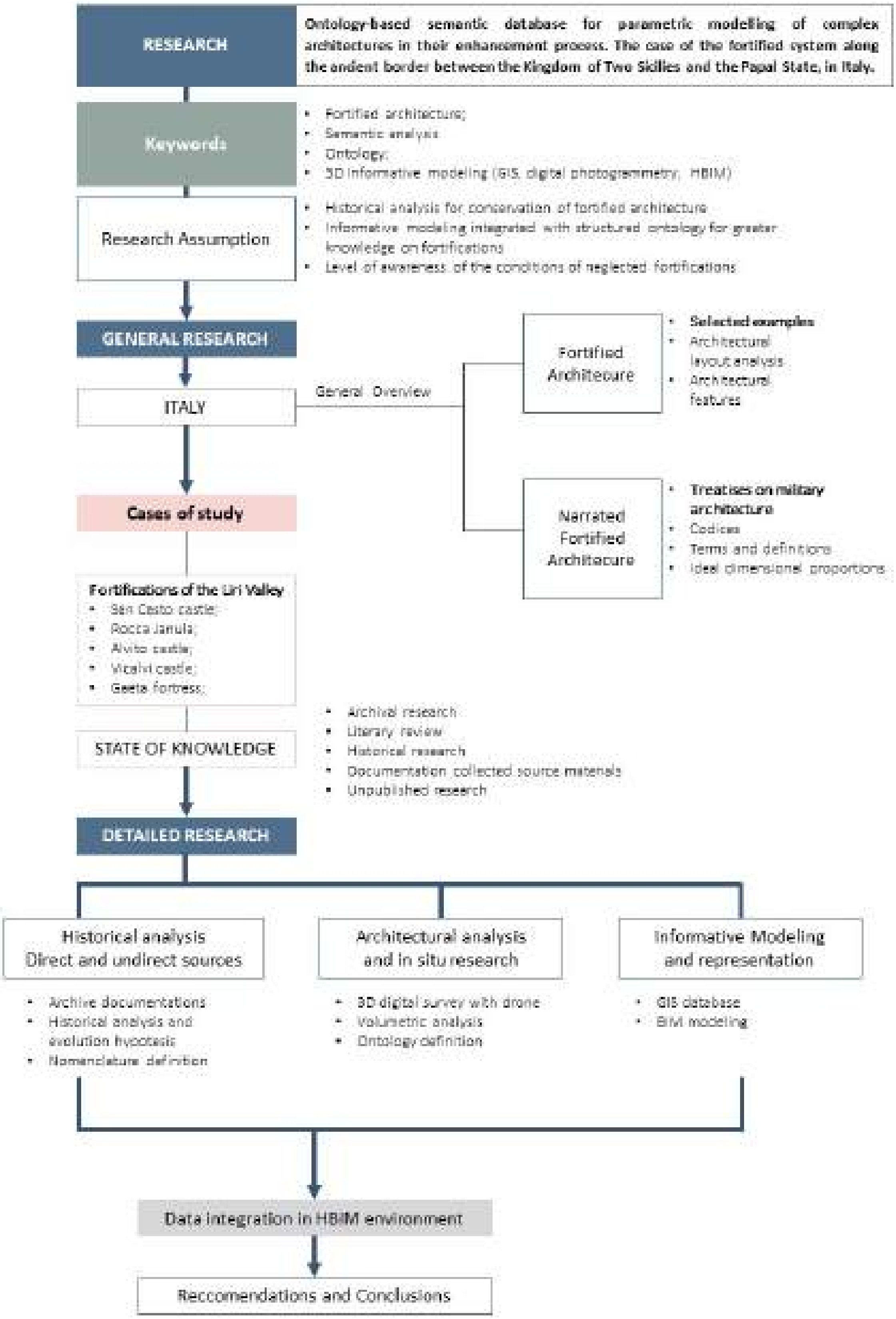


Fig. 6. Workflow Methodology adopted in the research (Author's elaboration)

6. Structure of the work



7. Definition of terms used in the research

This section aims to clarify the specific terminology employed throughout the research to ensure precision and consistency. The definitions provided are essential for establishing a common understanding of key concepts, especially those related to architectural history, fortifications, and digital methodologies. Given the interdisciplinary nature of this study, encompassing fields such as historical analysis, digital surveying, and restoration techniques, it is crucial to articulate each term with clarity. By defining these terms, the research sets a foundation for the subsequent discussion and analysis, minimizing ambiguity and enhancing the coherence of the arguments presented.

TERM	DEFINITION	SOURCE
Ontology	Regarding the essence of the architectural object and the finite elements that compose a fortress. A set of concepts and categories that shows the properties of the architectural objects and the relations between them. Ontology for architectural heritage is a formalized system of concepts and relationships used to describe and manage information about historical buildings and sites. It ensures the consistent representation of architectural features, historical data, and conservation information, facilitating data sharing and collaboration among stakeholders involved in the preservation of cultural heritage.	Pauwels, P., & Terkaj, W. (2016).
Semantization	Logical division of digital model's components according to their meaning. In architectural heritage models, the semantization can be realized a posteriori (reverse modeling processes) or a priori (for example Constructive solid geometry processes).	Brusaporci, S. (2015)

7. Definition of terms used in the research

TERM	DEFINITION	SOURCE
Enhancement	Revitalisation of a whole area by focusing on the relation between monument and landscape. The monument's revitalisation/ rehabilitation/ restoration (depending on the site's needs) is part of a broader process of rehabilitation and valorisation of the surrounding area. Enhancement in Architectural and Urban Areas refers to the process of improving the aesthetic, functional, and environmental qualities of buildings and urban spaces. This can include: - Aesthetic Enhancement: Improving the visual appeal of buildings and public spaces through architectural design, landscaping, and public art. - Functional Enhancement: Upgrading infrastructure, facilities, and amenities to better serve the needs of the community, such as adding parks, pedestrian pathways, and public transportation options. -Environmental Enhancement: Implementing sustainable practices and green technologies to reduce environmental impact, such as green roofs, energy-efficient buildings, and eco-friendly materials. -Historical Enhancement: Preserving and restoring historical buildings and landmarks to maintain cultural heritage while integrating modern functionalities.	Saccucci, M., & Pelliccio, A. (2018); Banfi, F., & Oreni, D. (2020).; Aiello, D., Fai, S., & Santagati, C. (2019); Spina, L.D., & Calabrò, F. (2018).

7. Definition of terms used in the research

TERM	DEFINITION	SOURCE
Architectural Heritage	Cultural heritage monuments are a group of buildings and sites, outstanding universal value from the point of view of history, art or science. In the modern theory of restoration, the qualities of a cultural heritage are the historical and the aesthetic values. An historical building is a complex system of spaces, volumes, materials, surfaces, constructive aspects, actual and past functions and configurations, degradation, etc. The whole is the result of a continuous historical process of modification and transformation. An architectural heritage can be interpreted as an "artifact", where its elements are witnesses of constructive cultures and of events occurred during the life of the building. In the study of architectural heritage is fundamental the archival analysis.	UNESCO 1972 World Heritage Convention; Brandi C., Theory of restoration; Carbonara g., (2020)
Information System	Tool for data management and elaboration. GIS was born for urban and territorial planning, while the first applications to cultural heritage have been made in the field of archeology. The first uses related to architecture were realized by applying the traditional GIS to two-dimensional drawings (plans and sections). Architectural information systems have been developed importing 3D models within GIS or using BIM for historical buildings.	Brusaporci, S. (2015) ; Pelliccio, A., Nowak, M. Z., & Saccucci, M. (2018).; Saccucci M., Miele V. (2022); Brumana, R., Et al, (2018)
Graphical Analysis	the use of visual tools and techniques to understand, represent, and communicate architectural concepts, forms, and structures. It is used to investigate spatial geometry, structural relationships, and the representation of architectural heritage.	Ródenas-López, M. A., Calvo-López, J., & Salcedo-Galera, M. (Eds.) (2022). Pelliccio, A., & Saccucci, M. (2020).
Informative Model	Complex Model made by the synthesis of geo-referenced architectural models and correlated databases. The Informative Model has to be able to visualize and computize synchronically and diachronically architectural information.	Brusaporci, S. (2015)

7. Definition of terms used in the research

TERM	DEFINITION	SOURCE
3D Model	Spatial model, made by digital solids and/or surfaces, able to simulate the architectural characteristics of a building (geometries, spaces, materials, historical and aesthetical values, etc.).	Brusaporci, S. (2015)
BIM	Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. BIM serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle; defined as existing from earliest conception to demolition; Building Information Modeling is the use of a shared digital representation of a built asset to facilitate design, construction, and operation processes to form a reliable basis for decisions.	National Institute of Building Sciences. (2015); ISO 19650-1:2018; Pelliccio, A., Saccucci, M., & Grande, E. (2017).
HBIM	Historic Building Information Modeling (HBIM) is a novel approach that incorporates the parametric modeling of historic structures, integrating traditional survey methods with advanced digital modeling techniques. HBIM provides a comprehensive framework for the management, conservation, and restoration of historic buildings by creating accurate digital representations of their geometry and condition.	Dore, C., & Murphy, M. (2012). Pelliccio, A., Saccucci, M., & Grande, E. (2017).
HBIM Ontology	Ontology in HBIM refers to the formal representation of knowledge as a set of concepts within the domain of historic buildings and the relationships between those concepts. It facilitates the standardization and interoperability of data, enabling efficient information exchange and management throughout the lifecycle of historic buildings.	Oreni, D., Brumana, R., Della Torre, S., Banfi, F., & Barazzetti, L. (2014). Giuliani, F., Gaglio, F., Martino, M. et al. (2024)

II

STATE OF KNOWLEDGE

MAIN LITERATURE

TYPOLOGY

DIGITAL TOOLS

State of Knowledge

Italian fortifications

1. The main literature on Italian fortified architecture

The state of knowledge of Italian fortifications covers a wide range of historical periods, architectural styles, and functions, reflecting Italy's complex geopolitical landscape. The research can be broadly divided into two categories: academic papers and monographs. Each offers a unique contribution to understanding these defensive structures' evolution, construction, and significance. Academic papers provide specific insights into Italian fortifications' technical, historical, and cultural aspects. They often focus on particular case studies, regional contexts, or technological innovations. Numerous papers concentrate on the fortifications in specific regions, such as Southern Italy (including Lazio, Campania, and Puglia), Northern Italy (notably Lombardy and Veneto), or Central Italy (Tuscany and Umbria). These studies emphasise the territorial importance of fortifications in the context of regional conflicts or as defensive mechanisms against foreign invasions. Another crucial body of papers addresses the technological advancements in fortification construction, such as the adoption of bastioned systems in the Renaissance or the transitional fortifications of the 16th and 17th centuries. These papers often use archaeological data,

Fig. 1 Thematic keywords orienting the literature review for building the State of Knowledge about Italian fortification phenomenon (Elaboration by the author)

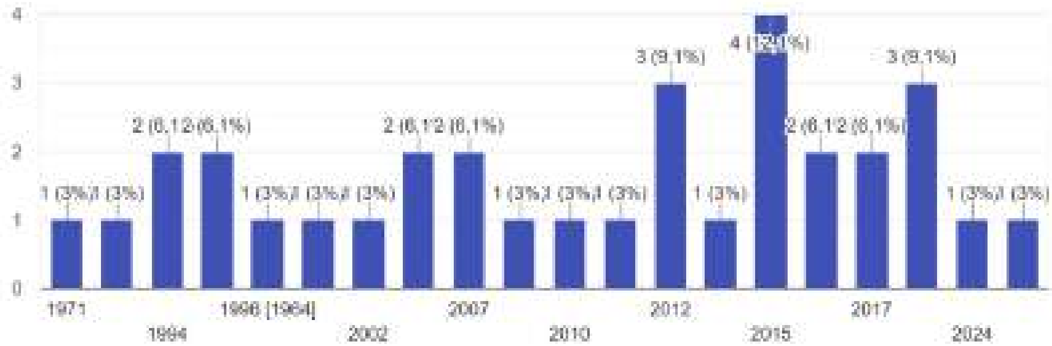


Fig.2 Histogram showing year of publications and sources identified by the author for building the SoTA on Italian fortifications. (Elaboration by the author)

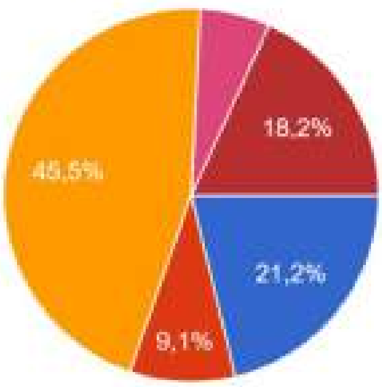


Fig.3 Pie chart showing percentage of the thematics identified in literature. (Elaboration by the author)

historical archives, and advanced surveying methods like Structure from Motion (SfM). More recent papers have explored digital technologies for reconstructing fortifications, such as BIM and 3D modelling. These approaches are valuable for studying the current state of ruins and their possible restoration. Monographs, in contrast, provide comprehensive overviews of Italian fortifications, covering broader periods or offering detailed studies of specific fortresses, cities, or regions. They often combine historical context with architectural analysis. Several monographs provide broad surveys of fortification developments in Italy, especially during critical periods like the medieval, Renaissance, and early modern eras. These works focus on how Italian fortifications evolved in response to changing military needs and political landscapes. Monographs dedicated to the construction techniques of fortifications, particularly during the Renaissance and early modern periods, examine the use of new materials, engineering methods, and the adaptation of Italian fortifications to deal with the advent of artillery. Some monographs delve into the cultural and symbolic aspects of fortifications, examining how they functioned as military structures and symbols of power, control, and prestige. This approach is often combined with art and social history to offer a multidisciplinary perspective. Both types of sources contribute to a deeper understanding of how these structures shaped and were shaped by Italy's military, political, and architectural history.

Italy, with its rich historical territory, was often fragmented into diverse political and cultural regions. These divisions fostered the creation of numerous fortifications, each serving defensive purposes and asserting territorial control. The traditional focus on individual castles, as if they were merely isolated objects of military science or aesthetic interest, has gradually shifted. Scholars have recognized that castles should be understood in conjunction with walled cities and urban cultures. This broader perspective was notably advanced by scholars like Paul Marconi, who argued that fortifications play an essential role in Italian national historiography, integrating military, architectural, and urban studies (Marconi, 1985). The works of Giulio Schmiedt and Gina Fasoli deserve recognition for their contributions to an integrated approach that views castles and walled cities as organic systems for territorial defense. Schmiedt's Città e fortificazioni nei rilievi aerofotografici (1974) and Fasoli's Feudo e Castello (1966) stand out for their rigorous, philological, and historical approaches, respectively, shaping our understanding of fortifications not merely as isolated artifacts but as part of larger defensive and administrative networks. Other scholars, working around the same period, highlighted how fortification design during the Renaissance was comparable in its artistic significance to more recognized architectural fields. Key figures such as Biagio Rossetti, Michelangelo, Bramante, Giuliano da Sangallo, Francesco di Giorgio, Leonardo da Vinci, and Albrecht Dürer engaged in the design of fortifications that were technically sophisticated and aesthetically comparable to their work in other architectural domains (Frommel, 1989). These fortified structures, defensive enclosures, and citadels are now considered an integral part of architectural history, requiring placement not just in the history of technology but in the broader history of art.

Fortified architecture benefited from a deeper understanding of Renaissance art history, a field to which Carlo Promis contributed in the 19th century, although his work faced difficulties due to the scarcity of documents and the limitations of a technical-military approach. Promis' pioneering contributions during the years of Italian unification laid the foundation for a more comprehensive view of fortified architecture, one that would later encompass both aesthetic and urban development elements (De Angelis, 1998).

The evolution of military architecture is closely linked to the development of weaponry and military technology. The fortified castle, which once served as a stronghold, residence, and refuge, underwent radical transformations with the invention of gunpowder and the development of artillery. The effectiveness of artillery increased gradually, leading to the adoption of bastioned fortifications, which replaced traditional medieval structures. This process was not instantaneous; there was a transition period of about fifty years during which both types of fortifications coexisted. Eventually, the bastion became the central element of fortified architecture, a system that remained dominant until the 19th century. This shift reflects the broader evolution of military tactics and architectural forms across Europe. Italian fortified architecture during this period is particularly well-documented in Fara's Le città da guerra (1993), which examines the relationship between military architecture and the surrounding environment. Fara's work reveals consistent patterns in the design and placement of fortifications from the late 15th century to the 19th century (Fara, 1993).

Fara's detailed analysis explores the work of prominent figures like Francesco di Giorgio, whose designs for fortresses were based on geometric principles that were influential in shaping fortifications for centuries. Similarly, the 18th-century citadel of Ignazio Bertola in Alessandria and the 19th-century forts of Giulio d'Andreis in Genoa continued this tradition of geometric precision. Starting with Brunelleschi's influence, Fara traces the evolution of fortifications through Leonardo da Vinci, Peruzzi, and the Sangallo family, showing how Renaissance architects applied sophisticated geometric systems to solve complex defensive challenges. This geometric underpinning of military architecture also extended to the design of new cities, from 16th-century foundations to the baroque layout of Turin and Vauban's fortified cities, all the way to the 19th-century Genoa of Giulio d'Andreis (Fara, 1993).

Cassi Ramelli's Storia dell'architettura militare (1996) is another important contribution, covering thirty centuries of fortification history. Ramelli's work addresses a wide range of topics, including literary sources, the reliability of historical testimonies, the challenges of terminology, and the development of new weapons and fortification strategies. His comprehensive approach includes not just the technical aspects of fortification design but also its philosophical and humanistic dimensions, contributing to a deeper understanding of how fortifications shaped societies and cultures throughout history (Ramelli, 1996).

In Luisi's (1994) article, the Italian contribution to military architecture is analyzed in greater depth, including the spread and influence of Italian fortification techniques across Europe. The Italian Renaissance saw the rise of drawing as a crucial tool for fortification design, with architects and military engineers using highly technical plans to visualize and communicate their designs. This practice was essential not only for the planning and construction of fortifications but also for the codification of new architectural norms. Studies like Zerlenga's (2020) on Iacomo Castriotto's Della Fortificatione delle città (1564) demonstrate the importance of geometric precision in Renaissance fortification, particularly in the creation of bastioned fortresses that adhered to Euclidean geometric principles.

Recent scholarship has also focused on digital reconstruction as a tool for preserving and understanding fortified architecture. Pirinu's (2008) doctoral research on the Palearo Fratino brothers, military engineers working in the service of the Spanish crown, is a noteworthy example. His research examines the Palearos' designs in Sardinia and other Mediterranean regions, using digital models to reconstruct lost or unbuilt fortifications. The integration of digital tools enables scholars to visualize the spatial dynamics of fortifications that no longer exist, offering a new way to engage with this rich architectural heritage.

Finally, Bevilacqua and Williams (2014) have explored the influence of Leon Battista Alberti on the emerging science of fortification in the 15th century, particularly through their analysis of the fortress of Vicopisano. Alberti's writings on fortifications informed Renaissance theorists and practitioners alike, providing a theoretical basis for the geometric design of defensive structures. Bevilacqua and Williams argue that Alberti's work bridges the gap between artistic and military architecture, demonstrating the interconnectedness of these fields during the Renaissance.

One significant gap in the current research on Italian fortified architecture lies in the underexploration of lesser-known regions and smaller fortifications, as well as the limited application of digital and virtual technologies in studying these structures. Much of the existing scholarship tends to focus on major, well-preserved fortifications in historically prominent regions in the north of Italy, in Tuscany, or around cities like Rome, and Naples, while many smaller castles and defensive structures in rural or peripheral areas remain neglected. These minor fortifications played crucial roles in local defense systems, yet they have not been systematically studied. The absence of comprehensive documentation and archaeological surveys of these sites leaves a significant gap in understanding the full scope of Italy's fortification network. Additionally, there is limited attention given to fortifications that have either deteriorated significantly or were destroyed over time due to warfare, and natural disasters. This gap can be further bridged by the expanded use of digital and virtual reconstruction technologies. While there are some promising examples of 3D modeling and virtual reconstructions being employed to study fortifications, the application of these tools remains sporadic. Digital technologies offer the potential to recreate lost or damaged structures, providing scholars and the public with interactive models that help visualize how these fortifications originally functioned and interacted with their environments. The integration of geographic information systems (GIS) would also enhance the understanding of how fortifications were strategically placed in relation to topographical features and surrounding landscapes. Furthermore, using virtual reality (VR) could bring these fortifications to life for educational purposes, allowing users to explore them in an immersive manner. By combining digital tools with traditional research methods, future studies could shed light on the less-documented aspects of Italy's fortification history and make these structures more accessible to a wider audience.

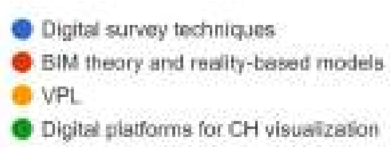


Fig.4 Thematic keywords orienting the literature review for building the State of Knowledge about Italian fortification phenomenon (Elaboration by the author)

2 State of knowledge of using digital methods and tools in conservation

The contribution to the literature review on digital techniques applied to the conservation and enhancement of architectural heritage focuses on outlining methods, procedures, and analyses that encapsulate the state of the art in research on the development of digital databases for Cultural Heritage. The review also addresses the integration of

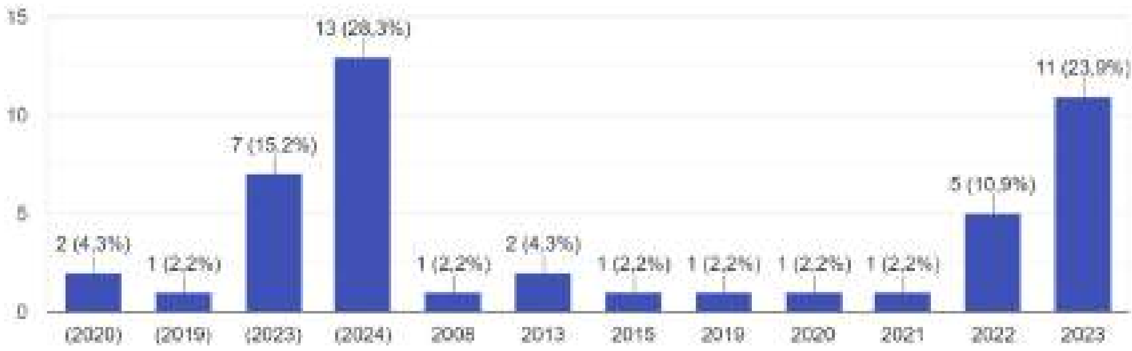
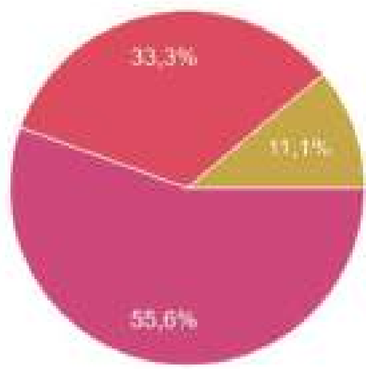


Fig.5. Histogram showing year of publications and sources identified by the author for building the SoTA on Digital tools and techniques. (Elaboration by the author)

modeling processes to create a holistic approach, capable of managing the complexity of cultural assets more effectively. Particular emphasis has been placed on recent scholarly contributions, specifically targeting studies published in 2022 and 2023. However, to ensure methodological rigor, earlier works were also incorporated due to their foundational relevance and continued applicability in the field.

The literature investigates four primary areas: the application of 3D surveying techniques for the virtual reconstruction of military architecture, methods for the semantic enrichment of HBIM (Historic Building Information Modeling) models, BIM-based digital platforms for the visualization of Cultural Heritage, and the relationship between BIM theory and reality-based models.



Fi.6 Pie chart showing percentage of the thematics identified in literature. (Elaboration by the author)

The theory of conservation in architecture has been profoundly influenced by the advent of digital technologies, such as Scan to BIM (Building Information Modeling), which have revolutionized the way heritage sites and buildings are documented, analyzed, and conserved. Historically, conservation practices were grounded in manual methods of documentation and analysis, such as hand-drawn surveys, which were labor-intensive and prone to human error. The introduction of digital techniques, particularly laser scanning and photogrammetry, has allowed for an unprecedented level of precision, ensuring that conservation decisions are informed by accurate and detailed data (Brumana et al., 2013; Lòpez et al., 2018).

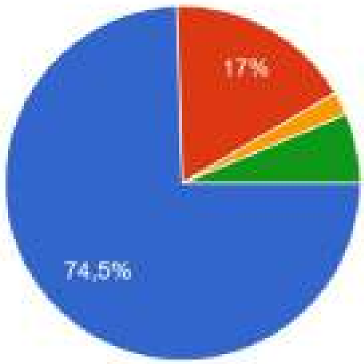


Fig.7 Pie chart showing percentage of the thematics identified in literature. (Elaboration by the author)

In the context of conservation, the Scan to BIM workflow involves the use of 3D laser scanning or photogrammetry to capture the physical structure of heritage buildings, which is then used to create detailed and data-rich BIM models. These models not only represent the building geometrically but also integrate data on materials, construction techniques, historical context, and structural conditions. This level of detailed documentation is essential for making informed decisions that adhere to core conservation principles, such as minimal intervention, authenticity, and reversibility.

One of the central tenets of conservation theory is minimal intervention, which advocates for preserving as much of the original structure as possible. Scan to BIM facilitates this by allowing for detailed analysis of the building's current condition, helping to identify areas in need of intervention while minimizing unnecessary alterations. This is crucial in maintaining the building's authenticity, a key concept in conservation charters such as the Venice Charter (1964), which emphasizes the importance of preserving the historical integrity of cultural heritage (ICOMOS, 1964). Moreover, by providing a comprehensive digital record, Scan to BIM supports reversibility in conservation—ensuring that any interventions can be undone in the future without compromising the original structure.

A major advancement brought by BIM technologies is the ability to conduct preventive conservation. Unlike traditional methods that are often reactive, Scan to BIM enables the simulation of different environmental conditions, material degradation scenarios, and structural loads, allowing conservationists to anticipate potential issues before they occur. This proactive approach is aligned with modern conservation theories, which advocate for ongoing maintenance and monitoring as part of the conservation strategy (Lopez et al., 2018). For example, by integrating sensor-based monitoring systems with BIM, it is possible to track environmental conditions in real-time, providing valuable data for maintaining heritage structures in a sustainable manner (Fai & Rafeiro, 2014).

Another key benefit of Scan to BIM is its ability to foster interdisciplinary collaboration. Conservation projects often involve a range of professionals, including architects, engineers, historians, archaeologists, and material scientists. The integration of BIM platforms enables all stakeholders to access and contribute to a centralized digital model, facilitating better communication and decision-making (Murphy et al., 2013). This aligns with broader trends in conservation theory, which stress the importance of a holistic and interdisciplinary approach to heritage management (Pocobelli et al., 2018).
Despite its advantages, the application of Scan to BIM in conservation presents several challenges. These include the high cost of laser scanning equipment, the complexity of accurately modeling irregular or decayed structures, and the need for specialized training to interpret BIM data effectively. Moreover, while BIM excels at documenting geometric and material information, integrating historical and typological data into the models remains a challenge, especially for complex heritage sites (Apollonio et al., 2020). Nevertheless, ongoing research and development in this field are making Scan to BIM an increasingly accessible and powerful tool in architectural conservation.

Digital aerial photogrammetry using drones has emerged as a vital technique for the documentation, monitoring, and analysis of architectural and archaeological heritage. This method, which involves capturing a series of overlapping images from a drone, has greatly expanded the potential for documenting large-scale or difficult-to-access sites (Pelliccio, 2021). These images are processed using photogrammetric software, often employing Structure from Motion (SfM) algorithms, to generate detailed 3D models and orthophotos. The resulting models are highly accurate, providing both visual and metric data that are crucial for heritage conservation (Westoby et al., 2012). One of the key advantages of using drones for photogrammetry is their ability to efficiently capture data over large areas or in challenging environments. For instance, in the conservation of cultural landscapes, drones can document not only individual heritage buildings but also the broader topographical context, which is critical for understanding the historical relationship between built structures and their natural surroundings (Chiabrando et al., 2017). This capability is particularly important in regions where heritage sites are integrated into complex landscapes, such as archaeological sites, fortifications, or urban heritage areas. Drones also provide a cost-effective solution for heritage documentation, as they reduce the need for scaffolding or other physical infrastructure that might otherwise be required for manual surveys. By flying over and around structures, drones can capture detailed images of elevations, rooftops, and other hard-to-reach areas, which are often neglected in traditional surveys. This capability is essential for documenting structures that are in a state of neglect or disrepair, where physical access may be limited or unsafe (Remondino et al., 2014). The integration of Ground Control Points (GCPs) enhances the accuracy of photogrammetric models, allowing for precise measurements that can be used in condition assessments and restoration planning (Bolognesi et al., 2014). These models can be overlaid with historical documentation, such as archival photographs or maps, providing a comprehensive understanding of changes to the site over time. This diachronic perspective is invaluable for developing conservation strategies that respect the historical evolution of the site while addressing current challenges.

One of the main challenges of drone-based photogrammetry is its reliance on suitable weather conditions, as factors like wind, rain, and lighting can significantly impact the quality of the data collected. Furthermore, the increasing use of drones has led to regulatory challenges, particularly in urban areas or near sensitive sites where flight restrictions may apply. Despite these limitations, advancements in drone technology, including the development of smaller, more agile drones with improved cameras, continue to expand the applicability of this technique (Colomina & Molina, 2014; Pelliccio, 2020).

In terms of data processing, Structure from Motion (SfM) has revolutionized the field by allowing 3D models to be generated from a series of 2D images. This method is highly efficient and cost-effective compared to traditional 3D modeling techniques, and it has proven to be particularly effective for documenting irregular or complex structures, such as ruins or buildings with intricate facades (Westoby et al., 2012). SfM-generated models can be integrated with GIS (Geographic Information Systems), providing spatial data that is crucial for the conservation and management of large heritage sites (Chiabrando et al., 2017; Saccucci et al., 2018).

Building Information Modeling (BIM) has become an essential tool for managing complex architectural and engineering data throughout the lifecycle of a building. In recent years, this technology has been adapted for the conservation of historic buildings through the development of Heritage Building Information Modeling (HBIM). HBIM extends the traditional capabilities of BIM by incorporating not only geometric and material data but also historical, typological, and cultural information, making it an ideal tool for the conservation and restoration of built heritage (Murphy et al., 2013).

The application of HBIM in heritage conservation enables the creation of highly detailed and data-rich 3D models of historical buildings. These models serve multiple purposes: they document the current state of the building with precision, facilitate the analysis of structural and material conditions, and provide a platform for planning and visualizing restoration interventions (Dore & Murphy, 2017). HBIM models can also integrate historical documentation, such as archival plans, photographs, and descriptions, allowing conservationists to develop strategies that are sensitive to the building's historical significance (Oreni et al., 2014).

One of the key advantages of HBIM is its capacity to manage the complexity of irregular or non-standardized structures, which are common in historic buildings. Traditional BIM systems, which are designed for modern buildings with standardized components, often struggle to represent the irregular geometry and unique materials found in heritage structures. HBIM addresses this challenge by using laser scanning and photogrammetry to capture accurate 3D data, which is then incorporated into the BIM model (Apollonio et al., 2020). This allows for the creation of detailed models that accurately reflect the building's geometry, enabling more informed decision-making during the restoration process.

HBIM is also particularly valuable for the conservation of neglected heritage, where years of abandonment or inadequate maintenance may have led to significant deterioration. By providing a detailed and accurate representation of the building's current condition, HBIM allows conservation professionals to prioritize urgent interventions and develop long-term restoration plans (Brumana et al., 2018). For example, HBIM models can be used to identify structural issues, such as cracks or deformation, and simulate the impact of different restoration techniques, ensuring that the chosen intervention is both effective and minimally invasive (Baik et al., 2014).

Another significant advantage of HBIM is its potential for predictive maintenance. By integrating real-time data from sensor systems, such as those that monitor temperature, humidity, or structural movement, HBIM models can be used to predict potential degradation and plan preventive maintenance accordingly (Fai & Rafeiro, 2014). This approach aligns with the broader shift in conservation theory towards preventive conservation, which emphasizes the importance of ongoing maintenance and monitoring to ensure the long-term sustainability of heritage structures (Pocobelli et al., 2018).

However, the use of HBIM is not without challenges. The creation of detailed HBIM models requires significant resources in terms of time, expertise, and technology. The process of scanning, modeling, and integrating historical data is complex and can be costly, particularly for large or intricate heritage sites (Murphy et al., 2013). Moreover, accurately representing the materiality of heritage buildings in HBIM models remains a challenge, as current BIM software is primarily designed for modern construction materials (Oreni et al., 2014). Despite these challenges, the continued development of HBIM tools and methodologies promises to make this technology increasingly accessible and effective for heritage conservation.

HBIM also plays a crucial role in the sustainable management of heritage buildings. By enabling precise documentation and analysis, HBIM supports the reuse of materials, optimization of energy efficiency, and reduction of environmental impact during restoration projects. This is particularly important in the context of neglected heritage, where the goal is often to restore the building to a functional state while preserving its historical and cultural significance (Fai et al., 2011). Moreover, HBIM models can be used to assess the environmental performance of restored buildings, ensuring that they meet modern sustainability standards without compromising their historical integrity. The utility of BIM (Building Information Modeling) in the construction sector is widely acknowledged, offering significant improvements in project visualization, data integration, and lifecycle management. In recent years, scholarly research has extended this exploration to cultural heritage, focusing on HBIM as a mechanism to deliver similar operability and insight for built heritage. Nonetheless, attempts to utilize BIM tools for cultural heritage management (CH) have revealed significant limitations, particularly in conveying information about cultural value and conservation activities. A prominent issue is the lack of standardized data in IFC (Industry Foundation Classes) formats that can facilitate the interoperability of these models across various platforms. As a response, the development of ontologies becomes essential for conceptualizing representative models of reality. Ontologies define specific classes, attributes, and relationships that describe a domain, enabling a deeper integration of knowledge representation and fostering model interoperability.

Moyano et al. (2023) provide a critical contribution by proposing a workflow that integrates ontological models specific to Cultural Heritage within a BIM environment, utilizing free and open-source software (FOSS). This approach empowers users to modify, enhance, and tailor functionalities to meet specific project needs. Their study also explores the interoperability of three BIM platforms—FreeCAD, ArchiCAD, and Revit—demonstrating the steps required for the exchange of data between geometric models and their corresponding semantic properties. This interconnection remains a crucial point of focus for ensuring that BIM models are not merely geometric replicas but are also semantically enriched repositories of cultural knowledge.

The importance of addressing semantic enrichment within HBIM models is echoed in the work of Cursi et al. (2022). They highlight the limitations posed by current software implementations and the challenges of establishing robust connections between BIM models and external knowledge resources. Their research seeks to examine the methods currently being tested to enhance semantic enrichment and extend the domain of knowledge representation. They identify two distinct approaches: one that focuses on the integration of external databases and another that enhances the internal capacity of BIM tools to support heritage-specific attributes. In the broader context of built heritage, BIM has demonstrated limitations in managing the extensive non-geometric information associated with heritage assets. This complexity is heightened by the need to account for material properties, historical context, and conservation activities, which are often difficult to represent within traditional BIM models. Simeone et al. (2019) address this issue by proposing a novel approach that integrates Semantic Web technologies to enrich BIM models, thereby satisfying the semantic representation requirements of built heritage. Their research presents an open structure, allowing for customization, scaling, and adaptation of the knowledge base to different artifact types and cultural activities. This solution enables a more comprehensive understanding and interpretation of cultural assets, enhancing decision-making processes in conservation and heritage management.

A growing body of research has also focused on the integration of visual programming languages (VPL) within BIM workflows, particularly in the context of architectural design. This integration allows for greater flexibility in automating repetitive modeling tasks and enhancing the parametrization of models based on architectural data. Recent experiments have inspired studies that explore the potential of combining BIM with VPL to address the specific needs of Cultural Heritage. This integrated approach underscores the advantages of HBIM for heritage assets, as it facilitates the integration of semantic and geometric data, thus providing a more nuanced understanding of cultural properties.

Further studies emphasize the role of parametric reconstruction techniques, often derived from primary historical sources such as treatises or textual descriptions. These methods enable researchers to recreate architectural objects with a high degree of accuracy, offering insights into the original design intentions and material composition of historical structures. Reality-based 3D models, derived from photogrammetry and laser scanning techniques, are also gaining prominence as tools for documentation and analysis within Cultural Heritage. These models provide a navigable, immersive environment in which reconstructed forms are based on historical surveys and sources. For instance, Manferdini et al. (2008) pioneered the development of reality-based 3D models of archaeological artifacts using photogrammetry and active sensor technologies. Their research introduced a semi-automatic segmentation method for classifying geometric models based on archaeological and architectural rules. The resulting models were linked to a comprehensive archaeological database, which facilitated the classification and interpretation of artifacts. Furthermore, these models were visualized in open-source 3D environments, providing heritage professionals with a powerful tool for monitoring and updating conservation strategies. The visualization of these models and the accompanying thematic layers serves as an invaluable resource for decision-makers in heritage management, offering a detailed and interactive representation of historical data. In conclusion, the application of digital techniques in the field of Cultural Heritage has significantly advanced the methodologies available for the conservation and enhancement of architectural heritage. From 3D surveying techniques and semantic enrichment of HBIM models to reality-based 3D reconstructions and parametric modeling, the research landscape reflects a growing recognition of the need for integrated, interdisciplinary approaches. The exploration of BIM and its extensions through ontologies, semantic enrichment, and reality-based modeling will continue to shape the future of cultural heritage conservation, ensuring that both geometric precision and cultural value are preserved for future generations.

According to Diara (2022), open-source solutions for HBIM have opened new avenues for research in digital heritage documentation, making technology more accessible and adaptable to specific project needs. By connecting paper-based and digital data, Scan to BIM allows for detailed visual and structural assessments without invasive physical interventions, aligning with the principles of minimal intervention and reversibility, core concepts in architectural conservation.
Another significant aspect of Scan to BIM is its potential to facilitate preventive conservation. Lovell et al. (2023) highlight that BIM's information management capabilities enable continuous monitoring and predictive analyses of building materials and structures, helping to address issues before they become critical. By integrating geometric data with information about the building's historical context, HBIM allows for a more nuanced approach to conservation, ensuring that restoration decisions are both structurally sound and sensitive to the building's historical significance. This is particularly useful in long-term maintenance strategies for heritage sites, where the goal is to extend the life of the structure while maintaining its historical authenticity.

Furthermore, the ability to integrate data from multiple disciplines into a central BIM model fosters collaboration between architects, engineers, conservators, and historians, ensuring that conservation efforts are well-rounded and based on a comprehensive understanding of the building's historical and material conditions (Murphy et al., 2013). HBIM has proven particularly valuable in addressing the needs of neglected heritage, where buildings may have suffered from years of disuse or inadequate maintenance. Murphy et al. (2013) explain that HBIM enables the accurate documentation of current conditions, which is critical for prioritizing interventions. For example, by identifying structural weaknesses or areas of material degradation, HBIM models can guide conservation efforts to focus on the most pressing issues first.

Another major benefit of HBIM is its role in preventive maintenance. By integrating real-time data from sensors, such as those monitoring temperature, humidity, or structural movement, HBIM models can be used to predict potential degradation and inform maintenance schedules. This aligns with the shift in conservation theory toward preventive conservation, where the goal is to minimize the need for large-scale interventions by maintaining the building in good condition over time (Fai et al., 2011).

Challenges remain, however, in the widespread adoption of HBIM. Achille et al. (2015) point out that creating detailed HBIM models can be resource-intensive, requiring specialized skills and equipment. Furthermore, accurately representing the materiality and geometry of heritage buildings, especially those with irregular structures, remains a complex task. Despite these challenges, advancements in both laser scanning and photogrammetry continue to improve the efficiency and accuracy of HBIM workflows, making this technology increasingly accessible for heritage conservation projects.

III

GENERAL OVERVIEW

ITALIAN FORTIFIED ARCHITECTURE TREATISES

GLOSSARY

General research Overview

1. General overview of the Italian fortification phenomenon

Fig. 1. Beato Angelico, Pala di Santa Trinita, (detail) 1345-40. Firenze, Museo di San Marco

A comprehensive overview of Italy's art of territorial defense, with a particular focus on the centuries-long evolution of fortified architecture, is essential in order to contextualize the development of strategic military constructions, understand the regional and political influences that shaped their design, and evaluate how these structures adapted to advancements in military technology and shifting geopolitical dynamics. This framework provides a robust foundation for more detailed analyses through the study of selected case examples. This chapter, therefore, focuses on selecting characteristic examples where relationships between multiple inhabited centers and their respective castles can be distinguished. The chosen examples are those in good condition, as this enables a better understanding of the fabric of relations between fortified structures, urban developments, and lookout points, avoiding reliance on purely archeological documentation. To further clarify these relationships, the chapter includes some 1:25,000 scale maps from the Italian Military Geographic Institute to clearly illustrate the relationships between defensive settlements, the topography, and municipal-level infrastructure. When possible, historical cartography is

Fig.2 Benozzo Gozzoli, Cappella Medicea (detail), Firenze, Palazzo Medici Riccardi

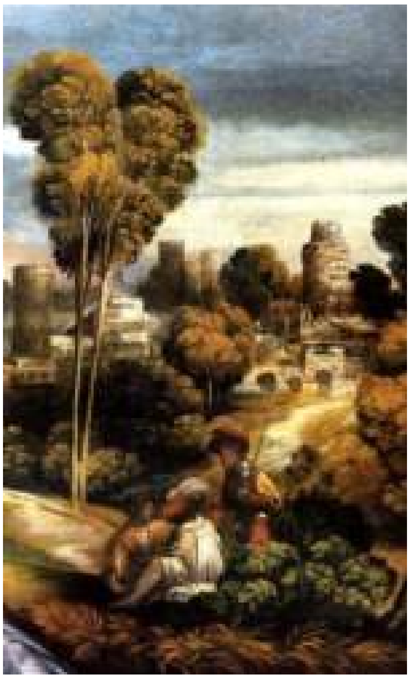


Fig. 3. Dosso Dossi, La maga Circe, (detail) ,1522-1524 ca, Roma, Galleria Borghese

included to show fortifications and walled cities in their original configurations. For Renaissance fortifications, documentation often comes from 16th-century notebooks, such as the Magliabechiana collection and ISCAG archives, which contain otherwise lost details of construction phases. Prints from the 16th and 17th centuries, as well as surveys from Napoleonic and Piedmontese military engineers, add further layers to the understanding of these structures .

1.1 Castrum, Castra, Castellum - genesis of the defensive concept

The Latin term castrum was originally linked to the verb castrare, meaning to "cut" or "trim," and it referred to a "piece or section of land." It is also possible that the term alluded to the act of cutting into the ground when preparing a basic fortification, the first step of which was digging a ditch. Castellum, grammatically a diminutive of castrum, as seen in a passage from Caesar [De Bello Gallico, 7, 69]:

"Castra opportunist locis erant posita, ibique XXIII castella facta" (The camps were placed in strategic locations, and there twenty-three smaller forts were built).

However, castellum soon took on an independent meaning: by the 4th century AD, Vegetius writes that "castellum parvulum burgum vocant" [Epitoma Rei Militaris, IV, 10], where it is evident that castellum was no longer considered a diminutive, as its smallness had to be emphasized with the adjective parvulum. Over time, castrum and castellum were generally used as synonyms, though exceptions existed.

During the Byzantine era, there was a hierarchical distinction between civitates (cities), castra, castella, and clusurae—terms which indicated different sizes and levels of importance. Even in classical Latin, words like castrum and castellum, as well as other terms referring to fortifications, often carried ambiguous meanings. Livy, discussing the possibility of an undefended castle, writes: "Si oppida castellacque immunita essent." Elsewhere, he seems to distinguish between vicus, meaning a lowland village, and castellum, a highland settlement, suggesting that altitude rather than fortification determined the distinction. In the first half of the 7th century, Isidore of Seville (Etymologies) also demonstrated some ambiguity. When discussing the oppidum (a fortified place serving as a refuge in wartime), he noted that it was larger than

a vicus, pagus, or castellum, with the defining difference being that an oppidum had walls—implying that a castellum might not. Later, however, he described a castrum as an oppidum situated at a high elevation, almost like a "tall house," and castellum as simply its diminutive. In the Latin Vulgate translation of the Bible, a literary model that heavily influenced the Middle Ages, castrum appears only three times, always tied to place names. In contrast, castellum is frequently used to mean a settlement, sometimes fortified, sometimes not, often alternating or in opposition with urbs, civitas, villa, viculus, and oppidum. This ambiguity in late antique texts inevitably carried over into medieval usage.[1]
The terms castellum and castrum thus encompassed a wide range of meanings, often very different from one another. They could refer to a fortification made of earth and wood at the head of a bridge, a stone wall surrounding monasteries, a populated settlement, sometimes even an episcopal seat, a fortified house in the city, or a royal palace, and so on. Lexically, civitas, vicus, castrum, and castellum were often used interchangeably according to a tradition that persisted into the early Middle Ages, with the exception of the plural castra, which always referred to a legionary encampment of some importance.[Settia, 2017].

The fortification-related meaning associated with these terms came much later, particularly during the process of incastellamento, which developed from the 10th century onward. Even in earlier texts, however, interpretive challenges arise. For instance, in reference to the castra of northern Italy, mentioned in George of Cyprus's Descriptio Orbis Romani, particularly the castra Emiliae built by the Byzantines and later taken over by the Lombards during the reign of King Liutprand. If we interpret castra as "territory" rather than "fortresses" [T. Lazzari, 2008], this implies a simpler territorial organization, without a strict hierarchy between civitates and castra, which may have predated the Lombard invasion. This interpretation reduces the military and fortified nature of settlements attributed to the Lombard era.

Yet, in late antique sources, there are instances where castrum and castellum clearly refer to fortified places. For example, Eugippius writes that between 492 and 496, the relics of Saint Severinus were transported from the Danubian region "ad castellum nomine Montem Feltrem"—to the imposing rock of San Leo, which was therefore fortified at least from the 5th century. Similarly, Cassiodorus's Variae offers a famous and

1. The term castello has a much wider meaning which often causes confusion.
A distinction should be made between a castello as an (often small) defensive structure and checkpoint in the rural landscape without habitation, and a castello as a fortified settlement, synonym for castrum. The latter castelli were much bigger and were the focal points of the incastellamento process. [Osheim 2004 & Bartolini 1987, the latter discussing the 12th century only.]

2. Settia, A., Proteggere e dominare. Fortificazioni e popolamento nell'Italia medievale, Rome 1999, pp. 149-151; see also Brogiolo, G. P., Gelichi S., Nuove ricerche sui castelli altomedievali in Italia settentrionale, Florence 1996, p. 14; Lusuardi Siena S., Sulle tracce della presenza gota in Italia: il contributo delle fonti archeologiche, in 'Magistra barbaritas'. I barbari in Italia, Milan 1984,.

significant description of a refuge castle:

"In Verruca castello vobis domicilio construatis, quod a positione sui congruum nomen accepit. Est enim in mediis campis tumulus saexus in rotunditate consurgens, qui proceris lateribus silvis erasus, totus mons quasi una turris efficitur."

This passage describes an elevated fortress built on a natural rock formation, referred to simply as castellum, without a doubt. Many other fortifications from the same era have been identified, located both on plains and at various altitudes. Recent research has demilitarized the term praetorium, which was previously interpreted in rural contexts as a fortified villa; similarly, depictions of villas with towers and other defensive features now appear to symbolize the power ambitions of their owners rather than actual military structures.

Until the mid-2nd century AD, the Roman Empire did not need to build fortifications, as the defense was provided by the metaphorical "wall" of its legions stationed along the borders. It was only in the following century, with recurring cycles of insecurity, that the borders began to be fortified. Soon, fortifications spread within the empire, signaling both the central authority's weakening grip and the growing need to protect the population from increasingly frequent and deep incursions by barbarian peoples. When, in 406, the barbarian tribes crossed the Rhine and entered Gaul, as recounted by Bishop Orientius, there were already walled cities and rural fortresses, but their number proved insufficient. Much of the defenseless population was forced to seek refuge in natural shelters: caves and hidden gorges in wooded areas, rugged mountain peaks believed to be inaccessible, and natural barriers such as rivers and seas—which often proved less impenetrable than imagined in the face of the skilled invaders [Settia, 2017].[2]

From this point onward, literary and epigraphic sources increasingly refer to fortifications that later historians have identified as first-generation castles.

Nevertheless, it is important not to over-define first-generation castles too precisely. In practice, it is difficult to distinguish between castles that served purely military functions and those built to provide refuge for local populations in times of emergency. For example, an inscription near Sisteron in Provence tells of a fortification created by Claudius Rossano Dardano, Praetorian Prefect of Gaul between 409 and 413, on his estate in a place called Theopolis (modern-day Théoux). Though not explicitly referred to as a castle, it is clear that it was a full-fledged fortification built for communal protection. Similar sites are mentioned by Sulpicius Severus and Gregory of Tours, typically located in highland areas where natural defenses were enhanced in late antiquity with walls. Some of these sites even contained churches and fields, forming an essential part of aristocratic estates and serving as dual-use settlements with evident refuge functions for the surrounding population.[Settia, 2017]

References

1. Caesar, G. I., & Maggi, A. (1947). De bello gallico. Chiantore.
2. Lazzari, T., 2008, Aziende fortificate, castelli e pievi: le basi patrimoniali dei poteri dei Canossa, pp. 96-115, Silvana Editoriale.
3. Settia, A., 2017, Castelli medievali, Il Mulino
4. Vegetius Renatus, F. (1995). Epitoma rei militaris. DE GRUYTER.

2. The architectural heritage of defensive Italian architecture from the Medieval era to the Renaissance

The enclosure, understood as a physical barrier placed to defend a populated area, even if small, remains the primary physical manifestation of a community's need for defense. Every innovation and progress in defense have always been directed towards it, at least until the 19th century and the Napoleonic wars. Already in the earliest fortifications of which we have evidence, the basic criteria of defense, based on high and thick walls, towers, and external moats, can be identified. Rodo Santoro marvelously cites the defenses of Jericho, (fig.4), dated by archaeologists to 8000 BC, which featured a stone wall with a tower and an external moat, and the Bronze Age fortifications of Chalandrianì on the island of Syros, with a circular wall and protruding semicircular towers. [Cassi Ramelli, 1996]

Fig. 4 Deep archaeological excavations at ancient Jericho (Tell-es-Sultan) conducted by Kathleen Kenyon in the 1950s. CBRL Archive

The criteria of defense, based on walls, towers, and moats, remained nearly unchanged in their main features until the introduction of firearms in warfare tactics at the beginning of the 15th century (fig.5). From that point onward, the natural evolution of fortification principles experienced significant acceleration: in just four centuries, an extremely unique experience was born, evolved, and exhausted, which saw the "bastioned front" as the foundation of urban and territorial defense systems. [Bevilacqua, 2007]

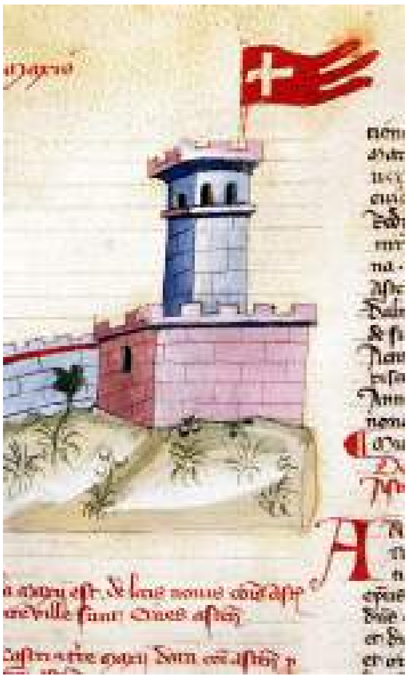


Fig.5 Masio, 13th century, the Tower outside the walls - miniature, Codex Astensis, Historical archives of the municipality of Asti

Fig.6 Rocca di Canossa, built in the 10th century, views from then hilltop and inside the remains. (https://www.italia.it/it/emilia-romagna - last access 25.09.24)

Italy's defensive architecture from the Medieval period to the Renaissance represents a critical evolution in military engineering, aesthetics, and political organization. As a highly contested space throughout its history, the Italian peninsula became a hotbed for military innovation and architectural development. This transformation was driven by constant warfare, both external and internal, as well as the changing political landscape of city-states, kingdoms, and the Papacy.
By tracing the architectural lineage from medieval fortifications to the sophisticated bastioned designs of the Renaissance, we can better understand how Italy's unique geographical and cultural context shaped its defensive structures.

The early medieval period in Italy was marked by fragmentation and insecurity, as the collapse of centralized Roman authority gave rise to a feudal system where lords and ecclesiastical powers competed for territory. Castles became the primary means of defense, often positioned in strategic locations to control trade routes and defend against raids.
The earliest medieval fortifications were modest in design.
Castles such as the Rocca di Canossa, (fig.6), built in the 10th century, were often perched on hilltops to provide a natural defensive advantage.
The structure's simplicity—relying on earthworks, wooden palisades, and later stone—demonstrated the need for quick construction during times of political instability. As Chris Wickham points out, "The fragmentation of political power in early medieval Italy necessitated the rise of localized fortifications to secure territories" [Wickham, 2015].
By the 11th and 12th centuries, as feudal lords sought to consolidate power, stone castles replaced earlier wooden structures. Castles such as Castel del Monte in Apulia, constructed by Frederick II in the 13th century, reflect the transition from purely military structures to symbols of authority and prestige [Heinz, 1994][3]. The distinctive octagonal form of Castel del Monte, with its symmetrical design and blend of Gothic and Classical influences, is considered a masterpiece of medieval military architecture. These castles were fortified with thick stone walls, towers, and defensive mechanisms like drawbridges and moats, exemplified by Rocca di Angera on Lake Maggiore.

The rise of communes in northern and central Italy during the 12th and 13th centuries introduced a new type of fortification—city walls. Cities like Florence, Siena, and Bologna invested heavily in urban defenses, building extensive wall systems to protect against rival cities. According to R. Smail, "Urban fortifications became vital for Italy's thriving city-states, whose wealth and political power were constantly under threat" [Smail, 1956]. The walls of Lucca, which still stand today, are an excellent example of medieval urban fortification designed to withstand sieges and protect against invasion. [Belli Barsali,1988]

Fig.7 Gateway to Ferrara Castle. (Photo taken by the author)

The 14th and 15th centuries saw a dramatic shift in military technology, particularly with the introduction of gunpowder and artillery. Traditional castles and city walls, built to defend against swords and siege engines, were no match for the destructive power of cannons. This necessitated a rethinking of defensive architecture. The rise of gunpowder in the 14th century revolutionized warfare and rendered many earlier fortifications obsolete. Castles that once stood invulnerable to siege were now vulnerable to cannon fire. Consequently, many Italian castles were modified with thicker, sloped walls and rounded towers to absorb and deflect the impact of artillery. The transformation of Castello Estense in Ferrara (Fig.7) in the late 15th century into a heavily fortified palace reflected this shift [Ghirardo, 1994].

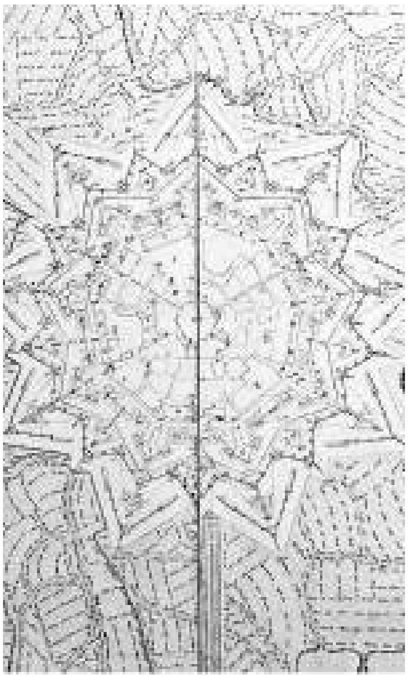


Fig. 8 Palmanova citadel plan, Napoleonic drawing (Monumenti d'Italia. I Castelli, Marconi P., a cura di, De Agostini)

The architectural response to the new realities of warfare came in the form of bastioned fortifications, designed to withstand artillery. Fortresses such as Sarzana, rebuilt in the 15th century with angled bastions and thicker walls, became prototypes for Renaissance military architecture [Tomei, 2009]. These innovations marked the beginning of the fortificazione alla moderna, or modern fortification style, which spread across Italy and influenced fortifications throughout Europe.

During the Renaissance, Italian defensive architecture evolved from purely functional military designs into a synthesis of art and engineering. The period saw architects and military engineers developing new techniques for fortifications while also embracing the humanist principles of symmetry and proportion. The Renaissance period marked a significant shift in how defensive structures were perceived. No longer simply utilitarian, fortifications became symbols of power and sophistication. The walls of Florence, reinforced by the Florentine Republic in the 15th century, were not only

3. Frederick II's urban planning policy was mainly dealt with by J.-M. MARTIN, Pouvoir, géographie de l'habitat et topographie urbaine en Pouille sous le règne de Frédéric II, in 'Archivio Storico Pugliese', 38 (1985), pp. 61-89 and ID., L'organisation administrative et militare du territoire, in Potere, società e popolo nell'età sveva (1210-1266), Bari 1985, pp. 71-121. Lastly, see the summary by E. GUIDONI, Urbanism and Frederick's architecture, in ID., Storia dell'urbanistica. Il Duecento, Bari 1989, pp. 61-82.

designed to protect the city but also to project the wealth and culture of Florence. As Paul Davies and David Hemsoll note, "Renaissance architects sought to harmonize function and aesthetics, creating structures that were both formidable and beautiful" [Davies & Hemsoll, 2014].

Italian Renaissance military engineers were among the most innovative of their time, blending scientific knowledge with architectural creativity. Leonardo da Vinci's designs for fortifications, such as those proposed for Imola, incorporated angled walls, sloped bastions, and other defensive features to deflect cannonballs [Kemp, 1981]. Michelangelo also played a role in fortifying Florence, designing a series of defensive walls and bastions to protect the city from siege in 1529 [Baldini, 1990]. The culmination of Renaissance military architecture in Italy came with the development of the star fort. These polygonal structures, designed to maximize defensive capabilities against artillery, featured multiple bastions projecting outward, allowing defenders to cover all angles of attack. The Cittadella di Palmanova, (fig. 8) built by the Venetian Republic in 1593, exemplifies the star fort's geometric precision and military efficacy. Palmanova's design reflected Renaissance ideals of order, proportion, and functionality [Cohen, 1976].This model would influence fortifications throughout Europe in the centuries to come.
Throughout the Renaissance, Italy's political landscape remained fragmented, with powerful city-states and foreign powers vying for dominance.
ortified cities became critical to maintaining control over territories, particularly in regions where external threats loomed large.

a. Venice and the defense of maritime power

Venice, one of Italy's most powerful and wealthy maritime republics, was deeply invested in fortifying both its mainland and island territories. The Venetian fortifications of Padua and Verona, designed by the military architect Michele Sanmicheli, demonstrated a blend of Renaissance aesthetics and cutting-edge military technology. These cities were fortified with bastions and artillery platforms to repel any potential invaders, whether from land or sea [Howard, 2004].

b. The Papal States and Rome's Fortifications

The Papal States also played a significant role in the development of Renaissance fortifications. Popes Nicholas V and Paul III invested heavily in reinforcing the defenses of

Rome, particularly at Castel Sant'Angelo (fig. 9), which had served as a fortress since ancient times. The fortification of the Vatican walls during this period not only served as a means of defense but also symbolized the temporal power of the papacy [Partner, 1972].

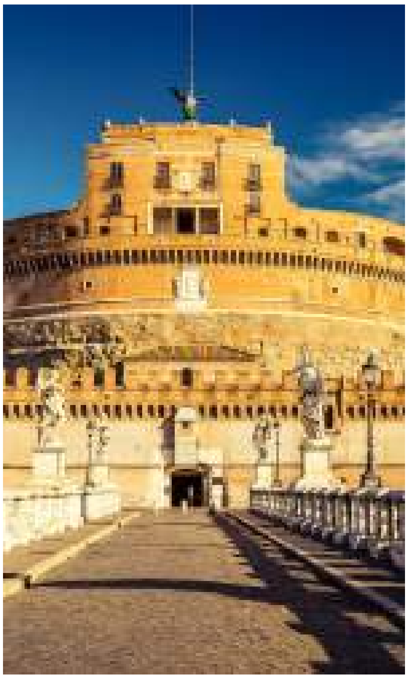


Fig. 9 Castel Sant'Angelo, Roma, (sborisov//Getty Images)

c. Southern Italy and the Kingdom of Naples

In southern Italy, the Kingdom of Naples experienced extensive fortification efforts during the Renaissance, particularly under the Aragonese rulers. Castel Nuovo in Naples, a massive fortress-palace, was redesigned to reflect both the grandeur of the Aragonese monarchy and the military requirements of the time. The castle's imposing towers and reinforced walls were key to protecting Naples from both external threats and internal rebellion .

As the political landscape changed in the 16th and 17th centuries, many Renaissance fortifications lost their military function and were transformed into palatial residences or administrative centers. The Palazzo Ducale in Urbino, for example, originally designed with defensive features, became a symbol of Renaissance culture and power. These transformations reflect the broader shift from medieval warfare to a period of relative peace and cultural flourishing [Camerota, 2002]. The geometric precision of Renaissance fortifications, particularly the star fort, influenced urban planning both in Italy and beyond. Cities like Palmanova were designed not just for defense but also to reflect the Renaissance ideals of order and symmetry. The radial layout of these fortified towns influenced the planning of new cities in Europe and the Americas in later centuries [Pollak, 1991].

2.2. The so-called "Transition period"

The historical period of "transition" in fortified architecture is characterized by significant transformations and experimentation, driven by the development of artillery and the evolving needs of military defense. This period typically spans from the mid-15th century, following the fall of Constantinople in 1453, to the siege of Florence in 1530, or more precisely, until the construction of the Fortezza da Basso in Florence in 1534 [Taddei et al, 2003]. This era reflects a shift from the medieval "plunging and striking" defense/offense system to the more modern "grazing fire" system, which persisted for centuries and involved extensive experimentation with the relationship between architecture (form) and

3. In 1479, Francione was commissioned to fortify Colle val d'Elsa together with Paolo di Francesco, Giuliano da Sangallo and Francesco d'Angelo known as il Cecca (of the works carried out, only the Porta Volterrana complex remains). Later, in 1485, together with Cecca, he was commissioned to build a large four-sided tower in Pietrasanta near one of the city gates, and to reinforce a section of the city walls. In the same year, together with Cecca and Domenico di Francesco, he designed and directed the construction of the citadel of Sarzana. The fortress, rectangular in plan, with cylindrical towers at the apexes and in the middle of the curtain walls, is divided internally by two defence enclosures, one of which contains, as in Volterra, the circular keep. Only seven years later, he began construction of the Sarzanello fortress. This has a triangular layout with circular towers at the apexes. The large triangular ravelin, placed to defend the entrance, was probably completed by the Genoese after the Florentines ceded the Sarzanesi lands to them. G. Severini, Architetture militari di Giuliano da Sangallo, Lischi, Pisa 1970, p.15, footnote 8.

weaponry (function). The fall of Constantinople in 1453, where large Muslim bombards devastated the city's walls, provided further impetus for innovation in fortified architecture. While artillery had been present in Italy for some time, the siege of Constantinople underscored the urgency of adapting to the increased power of firearms.
With the advent of artillery, direct fire became the dominant force in warfare, necessitating the redesign of fortifications. Italian architects began to design new fortresses that better incorporated artillery defense, moving away from the high towers and thin walls of medieval structures.
In Tuscany, Florence's expansionist policies fueled the development of important architectural workshops specializing in fortified architecture. Among these, Francesco di Giovanni di Matteo, known as "il Francione," was particularly influential. Working with apprentices such as Antonio and Giuliano da Sangallo, Luca del Caprina, and the da Maiano brothers, il Francione[3] contributed to the construction of the Rocca of Volterra (after the Alum War of 1476) and the walls of Colle Val d'Elsa, including the Porta del Sale. Simultaneously, in the Duchy of Urbino, Francesco di Giorgio Martini, the overseer of Siena's "bottini," designed numerous fortresses for Federico da Montefeltro and wrote a seminal treatise on fortified architecture. In addition to these figures, Leonardo da Vinci and Luciano Laurana worked on prominent fortifications in Urbino and the Marche region, including the Ducal Palace and the grand fortifications of Senigallia [Taddei, 2003].

This transitional phase aligns with broader cultural movements like the Humanist and Renaissance periods, where the interplay between form and function in architecture was increasingly emphasized. The fortress became the typical defensive structure of this period. Unlike the earlier medieval castles, fortresses were no longer residences for lords or castellans but were strictly military structures, designed to house garrisons and defend vast territories or cities. The garrison, led by a captain, maintained control of these complexes, reflecting the increasing militarization of fortified architecture.

A key feature of fortifications in this period is the continuous experimentation with forms and functions, as architects sought to develop optimal defense systems in response to artillery advances. This experimentation is evident in the mixture of architectural elements from both the old plunging defense system and the new bastioned systems. Fortresses in Tuscany, and elsewhere, were often the result of restructuring pre-existing works, leading to a blend of styles. Upper crownings, typically consisting of projecting machicolations with round or pointed arches, were a prominent feature in medieval architecture but became increasingly obsolete with the introduction of artillery. These elements were initially retained in early transitional fortifications like Volterra, Colle Val d'Elsa, Montepoggiolo, and Castrocaro. However, as the need for direct fire systems became more pressing, they were eventually eliminated in fortifications like Poggibonsi, Sansepolcro, Pisa, and Livorno [Taddei,D., 1987].

Fig.10 Fortresses of Sarzana and Sarzanello (Monumenti d'Italia. I Castelli, Marconi P., a cura di)

One of the most notable aspects of this transition is the evolution of the design of perimeter defenses, especially at the corners of fortifications. Initially, square towers dominated the landscape, but as architects like Francione, Laurana, Pontelli, and the Sangallos experimented with new forms, round and polygonal shapes became more prevalent. These shapes proved to be more effective against artillery fire. Round towers, such as those found at Sarzana, Sarzanello (fig. 10), and Volterra (fig. 11) provided several advantages: artillery shots from outside were more likely to glance off the inclined walls, and crossfire from within the fortress's embrasures became more efficient. This round shape also helped absorb the destructive effects of mining warfare, which posed a serious threat to fortifications during this period. Mining tactics involved tunneling beneath fortifications to collapse their walls, and the rounded design helped minimize the damage caused by such attacks.
In the latter half of the 15th century, a more mature understanding of artillery's impact on fortifications began to emerge. Architects abandoned orthogonal tower layouts in favor of polygonal perimeters with cylindrical towers at the corners, which allowed for more effective crossfire and artillery placement. These cylindrical towers, often projecting outward from the walls, provided flanking fire along the curtain walls, a key innovation in this period. The sloped bases of these towers and walls, along with the wider moats, further enhanced the fortifications' ability to withstand artillery fire.

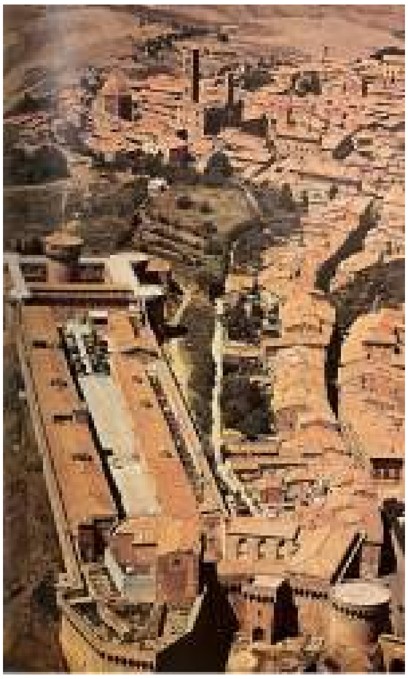


Fig. 11 Fortress of Volterra (Monumenti d'Italia. I Castelli, Marconi P., a cura di, De Agostini)

Tthe fortress of Volterra, designed by Francesco di Giovanni di Matteo (il Francione) in 1472. Volterra's design, with its quadrilateral layout, circular corner towers, and central keep, represents a transitional structure that incorporates both medieval defensive elements and Renaissance innovations. The spur at the Porta a Selci, for example, anticipates the formal parameters of the bastioned system that would soon dominate European fortifications[4] [Severini, 2001].

Fig. 12 Fortress of Serralunga d'Alba (Monumenti d'Italia. I Castelli, Marconi P., a cura di)

Il Francione's work between Tuscany and Lunigiana, including the walls of Colle Val d'Elsa and the fortresses of Sarzana and Sarzanello, exemplifies the architectural experimentation of the transitional period. His designs reflect the gradual but profound shift from medieval fortifications to modern bastioned systems, showcasing the evolving relationship between form and function in response to the new realities of artillery warfare.

As artillery evolved, so too did the shape of fortifications. The heart-shaped bastion emerged as a preferred design in fortresses like Pisa and Livorno, providing enhanced crossfire and better artillery placement. In some cases, polygonal shapes with sharp outer edges were used, such as in Brolio and Poggibonsi, where the grazing fire from within superimposed embrasures achieved superior offensive capabilities [Taddei,G., 2006]. This experimentation with shapes marked the search for an optimal defensive strategy in response to the increased use of artillery.

Another critical architectural element during this period of transition was the "throat of the bastion or round tower." This term refers to the area between the curvature of the round tower and the wall curtain, which was a key space for positioning artillery. In the early stages of experimentation, artillery was placed inside closed embrasures on the curvature of round towers, as seen in fortifications at Sansepolcro, San Gimignano, and Castrocaro. Over time, this element evolved, with the throat of the bastion being repositioned on a plane perpendicular to the wall curtain, as seen at Poggibonsi and Nettuno. Eventually, this design transformed into a semi-open space, allowing for artillery to be positioned in an open sky configuration, a feature that became prominent in fortifications like Pisa and Livorno [Taddei, 2003]. This design was later refined further, culminating in open-air artillery placements with barbette-mounted elements, as exemplified by the Fortezza da Basso, San Piero a Sieve, and Forte del Belvedere. These developments represent a significant evolution in the positioning of artillery, moving from enclosed spaces to more flexible, open-air configurations.

The increasing power of bombards and mines using gunpowder further catalyzed the development of new defense systems. Francesco di Giorgio Martini (fig.13) recognized the critical importance of these advancements, leading to his designs featuring angled walls, ravelins, and flanking fire (fig.14). This represented a shift in defensive structures from inside the fortress (plunging defense) to exterior systems (such as ravelins and distancing enclosures), marking a clear departure from medieval strategies. Martini's work laid the groundwork for modern bastioned fortification systems, which would later influence fortifications across Europe.

From the early 15th century, medieval fortifications, with their high perimeter walls of limited thickness and towering quadrangular structures, proved vulnerable to the emerging siege techniques that relied on breaching rather than scaling walls. In Filippo Brunelleschi's fortress at Vico Pisano, built in 1435, we see early signs of adapting to these new challenges. The fortress features a large square enclosure, modestly thick walls, and a high keep rising 31 meters at one corner. While Brunelleschi's design included some modern elements, such as a sloped base and gunports, which allowed for horizontal fire close to the ground, many features were still rooted in medieval tradition, like the very high square keep and battlements [Bevilacqua&Williams, 2014].

The systematic use of gunports in Brunelleschi's fortress reflects the early adoption of artillery, with gunports placed in regular rows at the base of the walls and on the elevated walkways. These gunports were characterized by short vertical slits or circular openings with posterior flaring, allowing defenders to fire projectiles horizontally. The sloped base of the walls also helped deflect artillery shots, another indication of the growing awareness of artillery's impact on fortifications [Bevilacqua,&Williams, 2014].

The design of Brunelleschi's Vico Pisano fortress included carefully planned internal compartmentalization, with the keep, fore-gate, and walls connected by elevated walkways and drawbridges that could be demolished in case of an attack. This feature allowed defenders to isolate sections of the fortress and retreat to more secure areas, reflecting a strategic approach to layered defense. Although this design was soon rendered obsolete by more powerful firearms, it demonstrated Brunelleschi's forward-thinking approach, which relied heavily on geometric precision and optical control, principles that would influence later developments in fortification design [Bevilacqua&Williams, 2014].

4. Although it presents a modestly sized flank for the grazing defence of the southern curtain of the fortress, the strut should only be partially embanked and without internal cavities. G. Severini, La fortezza, in 'Laboratorio Universitario Volterrano, Quaderno IV', Pisa, Edizioni ETS, 2001, p. 17. ; Cadei A., Modelli e variazioni federiciane nello schema del castrum, in Frederick II. Convegno dell'Istituto Storico Germanico di Roma nell'VIII centenario della nascita, edited by A. Esch, N. Kamp,Tübingen 1996, pp. 465-485 (Bibliothek des Deutschen Historischen Instituts in Rom, vol. 85). 5 On the action of Frederick II in Tuscany see the recent synthesis by M. Ronzani, Pisa e la Toscana, in Federico II e le città italiane, edited by P. Toubert, A. Paravicini Bagliani, Palermo 1994, pp. 65-84. 6 Il castello dell'Imperatore a Prato, edited by F. Gurrieri, Prato 1975.

2.3 Francesco di Giorgio Martini's work

Fig. 13 Portrait of Francesco di Giorgio Martini, in Le Vite, Vasari (1568)

Fig. 14 Illustration by Francesco di Giorgio Martini, in Trattato di Architettura civile e militare

The importance of Francesco di Giorgio's role in this phase is well known, to the point that, following Promis, he is attributed the paternity of the bastion based on some drawings from the Magliabechiano Codex. In the codes recognized as belonging to his treatise, including the Magliabechiano, Francesco emphasized the need for a strongly geometric organization of the fortified perimeter, ensuring flanking defense with adequately long straight curtains. However, he insisted on the value of the circular plan, to be used exclusively for corner towers and not extended to the profile of the curtains. From reading the drawings in the codex, there is a continuous search for perfection of angled profiles, better suited to realize the idea of "escaping walls." Fara writes:

"In Francesco, the spur, like the rhomboidal layout in general and the ravelin, has the meaning of directing salient angles towards the besieger's bombards, offering inclined, 'escaping' surfaces to perpendicular shots."

In the reconstruction of the Lombard fortress of San Leo between 1476 and 1478, commissioned by Federico da Montefeltro, Francesco di Giorgio inserted an angled curtain towards the outside, included between cylindrical corner towers formally similar to those of Il Francione in Volterra. The combination of angled and round shapes is found in other drawings of the codex, such as the theme of the cylindrical tower placed on the salient of a spur, studied to allow reverse fire and later realized in 1507 in the Gallipoli fortress by Gian Giacomo dell'Acaya based on Martini's design. While the issue of the bastion's paternity appears irresolvable, it is certain that Francesco di Giorgio's treatise formalized some fundamental aspects of the new military architecture, such as the ditch, the covered way, the glacis, the ravelin, and the "capannato." The latter, claimed by Francesco as his invention, consisted of a sort of low gallery with strategically placed gunports, to be located at the corners of the fortress walls. These bodies, very advanced towards the moat, could be connected to the walls by an underground passage.
If the attribution of the bastion to Francesco di Giorgio cannot be determined, his contribution lay mainly in the originality of his treatises, the richness of the solutions proposed, and being the first to write about the importance of the construction site, to which he unusually dedicated the beginning of his dissertation because, as Addams writes,

"architectural forms that adapt to the site with the fluidity of water can be directed to create a solid defensive work."
His treatises on architecture, engineering, and military art, slightly postdating 1480, represented the first in a long line of theoretical writings; his notebooks, his accurate intuitions on flanking fire, and the indispensable solidarity of all parts engaged in defense preceded specialized literature by at least half a century.

Francesco di Giorgio Martini's Treatise on Architecture,[5] particularly the manuscript version known as Ashburnham 361, held in the Biblioteca Laurenziana in Florence, has been the subject of significant scholarly inquiry. While much of the research to date has focused on the treatise's literary content and the detailed miniature illustrations that accompany the text, recent studies have concentrated on the manuscript's first section, which is devoted to military architecture. Through a critical analysis of this section, supported by previous research, scholars have been able to explore the intricate relationship between the text and its corresponding drawings. This examination has provided valuable insights into the types of fortifications depicted by Francesco di Giorgio, revealing details about their construction and how they operated in both defensive and offensive contexts.
Ashburnham 361 is one of the few surviving illuminated manuscripts of Francesco di Giorgio's Treatise on Civil and Military Architecture. One of its most remarkable aspects is its connection to Leonardo da Vinci, who referenced this manuscript in the Madrid Codex II (folios 2v and 3r). To this day, it remains the only known manuscript definitively in Leonardo's possession, evidenced by his annotations and sketches on eight of its pages. The treatise, reproduced in a facsimile edition by Marani in 1979, covers a wide range of topics, including civil, religious, and military architecture, as well as hydraulic engineering, water management, and metal casting. As such, it is a comprehensive technical manual for late fifteenth-century architectural and engineering practices.
The Ashburnham 361 codex, with its use of the vernacular language and exceptional quality of illustrations, is a significant work. The drawings, executed by a masterful illuminator, were not merely decorative but essential to conveying complex architectural concepts. This combination of text and image reflects the medieval construction culture in which Francesco di Giorgio was immersed. While the manuscript's origins have been traced, the exact date of its creation remains uncertain. Ongoing research continues to shed light on the treatise's

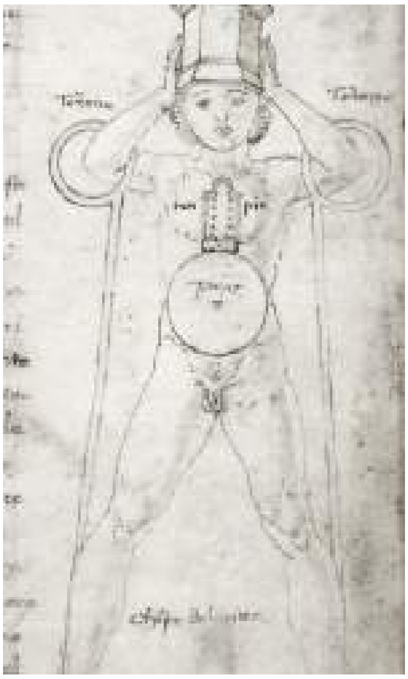


Fig.14 Di Giorgio Martini. Representation of the fortified city in human form, Trattato di Architettura civila e militare, 1470 ca.

Fig. 15 Drawing by Leonardo Da Vinci, Codice di Madrid II, 37r. - Fortezza del Monte a Santa Maria, c. 1504.

5. The main guide to the study of the fortification system examined in the present research is the architectural theories developed by Francesco di Giorgio Martini, which bear the influence of excellent masters whose details he retraced or reworked, now traced in the manuscripts and codices collected in the "Treatises" attributed to the architect. Giorgio Martini's work revolves around three fundamental writings: Treatise I - Architecture, Engineering and Military Art, testified by the Turin manuscript Saluzziano 148 and the Laurentian codex Ashburnhamiano 361; the translation of De Architectura, testified by Codex Magliabechiano II.I.141; and Treatise II - Civil and Military Architecture, of which two manuscripts have been handed down: Senese S.IV.4 and Codex Magliabechiano II.I.141.From these codices emerge the knowledge of the theories of Mariano di Jacopo (Taccola), Alberti, but more than anything else, the dictates of Vitruvius. At the same time, Martinian texts inspired numerous artists, including Leonardo da Vinci, who studied and commented on the Laurentian Ashburnhamian Codex 361. The fortune of Codex Saluzziano 148, by Cavaliere Cesare Saluzzo (1778-1853), contributed to disseminating the subject of Martinian fortified architecture.

development, showing how Francesco di Giorgio's ideas evolved, particularly in relation to earlier works, such as Vitruvius' De Architectura.
Additionally, an analysis of the manuscript's illustrations suggests they do not follow the strict rules of geometric representation typically associated with Renaissance drawings. Instead, they align with a medieval tradition, where the purpose of these images was not technical precision but rather the communication of conceptual ideas. These concepts are further explored in the text, offering a more interpretative and flexible approach to architectural representation [Bertocci, 2022].

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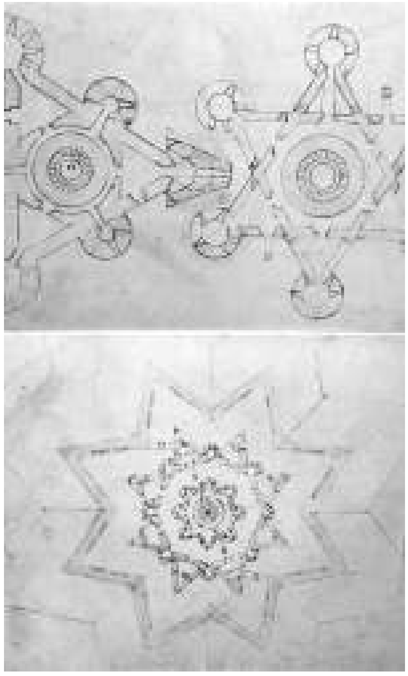


Fig. 16 Giuliano da Sangallo, Sienese notebook depicting fortresses with a hexagonal layout and one with an octagonal layout.

2.4. Fortified architecture “alla moderna” or bastioned fortress.

The more mature work of Antonio the Elder and Giuliano da Sangallo reflects in the correct formulation of the typological parameters of the bastion or "Italian" bulwark, as a truly innovative defense structure. In the few sheets dedicated to fortifications, drawn by Giuliano da Sangallo in his Sienese Notebook, theoretical elaborations of fortresses appear that only superficially reflect Martini's experience. (Bevilacqua, 2008). In the first sheet, the fortress perimeter has a strongly rational root, based on the intersection of triangular geometric figures. The fortification of the circuit angles is entrusted to cylindrical armed towers and a polygonal spur. In the second example, also purely theoretical, flanking is significantly improved: a hexagonal nucleus with exclusively cylindrical corner towers unfolds around a radial central structure.
A third theoretical elaboration, certainly later, concerns the general features of a quadrangular fortress, constituting the prototype of the fortresses built by the Sangallo brothers from the late 1400s to the 1520s; in this example, the cylindrical shape is reserved for a "central keep," while the fortress is

defended by polygonal corner towers, sloped walls with moats, glacis, and ravelins, the latter aligned with the access points.
Analyzing the projects of Poggio Imperiale, Civitacastellana, Nettuno, Sansepolcro, Arezzo, the fortresses of Castrocaro and Verruca, the San Marco fort in Pisa, and the "old" fortress in Livorno, it is possible to recognize the maturation of the Sangallo brothers' military architectural language and the formalization of the geometric principles of the new Italian defensive front.
Already from the first projects at the Poggio Imperiale fortress in 1488, Giuliano concretized a regular perimeter based on flanking rules and defended by polygonal corner towers that can already be defined as "bastions."
In the project at the Civitacastellana citadel in 1493, Antonio introduced the presence of oreillons to defend the open gunports on the flank. The theme of the recessed, concave, or rectilinear flank with gunports for horizontal defense protected by masonry shoulders - the so-called "oreillons" or "musons" - became a distinctive and original feature of the military architecture of the two brothers, particularly Giuliano. This device was reiterated and perfected in almost all the Sangallo brothers' projects, from the fortresses of Nettuno and Arezzo between 1501 and 1503, to the concave recessed flank with convex oreillon and double order of gunports of the fortresses of Pisa between 1509 and 1512, and Livorno between 1519 and 1533, the latter exclusively designed by Antonio after his brother's death.
The bastions in these fortresses are still entirely made of masonry. The configuration of the elevation profile, which in the latest examples shows height ratios close to those indicated by the sixteenth-century treatises, however, reveals a persistent formal attention to decorative aspects, which the Sangallo brothers borrowed from civil architecture.
The application of theoretical models based on strictly geometric parameters did not find slavish observance in the Sangallo brothers. Martini's lesson on the necessity of adapting the design idea to the site's conditions is found in the drawings of the two brothers in some otherwise unjustifiable irregularities. In the Poggio Imperiale fortress, for example, the front facing the city shows a reduced slope surface, contrary to the one facing the outside, more exposed to artillery fire. In the Civitacastellana citadel, the asymmetry due to the different orientation of the curtains was caused by the terrain's conformation, whose tufaceous rock banks were incorporated into the curtains. In light of this, if the issue of the bastion's paternity appears irresolvable, it is certain that the Sangallo

brothers' citadels represent the most significant architectures of fortifications from this period. When in 1507 Gian Giacomo dell'Acaya was building the Gallipoli castle with spurs still featuring cylindrical towers at the vertex, Giuliano and Antonio had already built citadels where the main element was the bastion with recessed flanks and oreillons. Perhaps this scheme also originated from Francesco di Giorgio's drawings, but the Sangallo brothers reworked it into an original architectural style. For this reason, it is considered that if one wishes to continue rigidly dividing fortifications into epochs, their experience was emblematic, as it concluded the "transit" era and inaugurated the "modern" fortification era with all the subsequent experimentation.

3. The practice of treatise Italian writers in military architecture

Between the late 15th and mid-16th centuries, profound political and economic changes were recorded. The birth of nation-states definitively ended the agonizing experience of small city-states. Power was centralized in the hands of absolute sovereigns who, with more efficient bureaucratic apparatuses and substantial capital, began a policy of armaments and territorial expansion with an unprecedented deployment of forces, men, and means.
Alongside France and the Empire, in the mid-16th century, only a few Italian states, such as Florence and Venice, managed to play an important political role, possessing efficient state structures and substantial capital for armaments and territorial fortification. It was in these realities that the "science of war" developed, with the theoretical, technological, and architectural aspects that characterized it.
In this context, architects, engineers, and military men, favored by a culturally vibrant environment, began writing treatises on fortifications and the art of war. This process, which initially was essentially an Italian phenomenon, was exported abroad by Italians in the service of major European powers.
In the early 1400s, military architecture treatises still reflected a philological attitude towards late ancient texts by Vitruvius and Flavio Vegetius Renato (Epitoma rei militaris around 1400). This is demonstrated by the first printed military treatise, Roberto Valturio's De re militari libri XII, which, however, gave ample space to illustrations and communication through images.
For Alberti, Filarete, and Francesco di Giorgio, fortifications were still an integral part of a broader conception of

architecture. In the second draft of his Treatises, Francesco di Giorgio perhaps first expressed the need to adapt his projects to the new developments in siege techniques, making the engineering aspect one of the main features of his writings. The first half of the 1400s saw the compilation of De machinis libri X, a compendium on war machines written by Jacopo Marino, known as Taccola, which greatly influenced subsequent mechanical studies, including Francesco di Giorgio's work.
In 1521, Giovan Battista della Valle di Venafro published Vallo, a manual emphasizing the advantages of earth fortifications over masonry, as they provided better resistance to artillery, were cheaper, and caused less damage to soldiers during attacks. Around the same time, Albrecht Dürer developed a theory of fortifications based on circular designs, as opposed to the polygonal bastions being tested in Italy by the Sangallo brothers. Dürer's ideas, published in 1527, were primarily geometric, featuring earthen embankments with sloped walls and artillery positioned at different levels, but his treatise remained largely outside the Italian tradition of fortification.

Dürer also envisioned a utopian city, where concentric circular walls served as fortifications and a hierarchical social order was organized around a central square. In this ideal city, capable artisans, soldiers, and defenders were assigned specific roles in service of the castle.
As firearms spread, the science of ballistics became crucial for military engineering, leading to a deeper understanding of defense design. Niccolò Tartaglia, in Nova Scientia (1537), advanced this field by challenging the Aristotelian theory of motion, introducing the idea that gravity continuously affects a projectile's trajectory. His studies influenced later scientific developments, including Galileo's work on motion.
The frontispiece of Nova Scientia symbolizes the relationship between fortification techniques, mechanical sciences, and mathematics. It depicts Euclid at the entrance to a walled circle, where Tartaglia illustrates the path of a cannonball, while Plato, at a second gate, holds a scroll that suggests the importance of geometry in both theoretical and practical applications of modern fortifications. This image highlights the shift from theological influences to empirical, science-based methods in fortification design.

A list of the codices and treaties that were considered for the study and design of the ontology related to the detailed case studies follows:

Title	Type	Year	Author	Place	Specifications
Trattato dell'Architettura Civile e Militare	Treatise	1481–1486	Francesco di Giorgio Martini	Various	Theory of architecture; Geometric analysis; Semantic Analysis
Codice Saluzziano 148	Treatise	1841	Cesare de Saluzzo	Biblioteca Reale di Torino; Biblioteca della Soprintendenza per i Beni Architettonici e per il Paesaggio delle Marche	
Codice 383 – Disegno di una pianta di fortezza	Codex			Biblioteca Reale di Torino	
Codice Laurenziano Ashburnhamiano 361	Treatise			Biblioteca Mediceo Laurenziana di Firenze	With drawings and notes by Leonardo
Codice Magliabechiano II.I.141	Treatise		Cesare Magliabechi	Biblioteca Nazionale di Firenze	According to C. Promis, the second edition of the Treatise of FdGM, where the architect moves away from the traditional medieval model to conform to the ideal figure of the architect outlined by L.B. Alberti in "De re Edificatoria"; commented by Leonardo
Codice monacense Latino 197	Codex		Mariano di Jacopo detto il Taccola	Biblioteca Sta tale Monaco di Baviera	Prototreatise handed down as a copy from Codex Zichy (most likely the first edition of the treatise compiled by FdGM between 1480 and 1482)
Disegno N. 52 della Rocca di Cagli.	Document			Accademia di Belle Arti di Firenze	Unlike the one represented in the "Magliabechian" codex, it bears an autograph inscription
"Fogli reggiani"	Document			Biblioteca Municipale di Reggio Emilia	44 pen drawings containing the chapter on ancient and modern military machines, which continues the final paragraph of the Hashburnhamian Code 361

Title	Type	Year	Author	Place	Specifications
Foglio n. XXI. 7. dei 10 fogli della collezione "Chigi Saracini"	Document	1498 – 1501	FdGM Attributed		perspective view of a fortification bounded by an angled primary symmetrical enclosure, scarped on wooden palisades and "embanked." The enclosure has two large open entrances along the longitudinal axis and encloses within it a huge breech-loading bombard. The ten sheets are membranous, unbound, anepigraphic, and adesoptic.
Appunti autografi su alcuni disegni dal n. 318 al n. 337. Nel Disegno n. 336 A	Document			Galleria degli Uffizi	Fortified Palace project, the current shape of the bastion front composed of towers with eaves is traced for the first time
De re militare,	Treatise	1472	Roberto Valturio		
Nova Scientia. Quesiti et invenzioni diverse.	Treatise	1537 1538	Nicolò Tartaglia		Tartaglia's studies constituted an important scientific reference point, to the extent that the connection with his theory is also felt in the definition of the law of motion of material bodies proposed by Galileo in the small treatise De Motu in 1590
Trattato delle Fortificazioni	Treatise	1545 -98.	Giovan Battista Belluzzi,		Bellucci's work, considered the first treatment by a purely military engineer, constituted a significant reference point for subsequent treatises.
Architettura militare	Treatise	1565 1599	Francesco de Marchi		De Marchi's first book, together with Cataneo's, was the first comprehensive exposition in urban planning. By the mid-16th century, the ideal radiocentric city model was widely shared. This scheme, with much older roots, proved fundamental in modern urban planning based on military needs. In fact, radial roads, connecting central city areas with city gates, perfectly met military control requirements in all spatial directions.
Le Fortificationi	Treatise	1609	Bonaiuto Lorini		

The following is an excerpt of the nomenclature resulting from the study of military architecture dictionary by D'Ayala, the work by Cassi Ramelli (1996), and the resources made available by the Istituto Italiano Castelli (https://www.istitutoitalianocastelli.it/- last access 25.09.24)

Name	Definition
Abbattuta	obstacle consisting of overturned trees to impede the enemy's march. It was usually made up of several successive rows detached from each other, to prevent a fire set to the first one from destroying the entire arrangement. In some cases, to give greater consistency to the obstacle, tree trunks were tied together.
Affusto	support of various types for a muzzle. Depending on their use, shafts are divided into mobile or fixed; each of the two categories is then divided into various subcategories: a. siege, square, coast, campaign, and so on.
Aggere	earth, masonry, or rubble elevation erected to defend encampments, typical of the Roman fortification tradition.
Aggetto	In late medieval fortifications is the projecting battlements (projecting apparatus), which give maximum effectiveness to the plumbed defense.
Andito D'accesso (Androne)	covered space, usually guarded by a tower, located immediately inside the entrance gate or drawbridge of a fortified gate.
Angolo Di Gola	fundamental parameter for the design and description of rampart architecture. It is the angle formed by the ideal extension of the two curtains placed at the base of a bastion.
Angolo Morto	area located behind an obstacle, and thus defiladed from any projectile.
Antemurale	light fortification, built of different materials (masonry, felled, earth) and by various means and placed in front of a line of defense, so as to be the first obstacle encountered by the assailant.
Antifosso	ditch in front of the main moat, so as to double its defensive effectiveness.
Antiporta	External protection placed before an entrance. It is a device adopted to further defend the gate of a fortification by dampening the first rush of the assailant.
Apparato A Sporgere	defensive system that came into use in the late Middle Ages and consisted of having the patrol walk projecting from the curtain wall below, so as to allow lead defense (see). It remained in use in our country until the late 15th century.
Arcata Di Aggettatura	projecting battlements or patrol walkway that rests not on a simple corbellation but on a succession of arches.
Archetto	architectural element, used to connect the corbels of the projecting battlements, but also sometimes used to directly support the projecting walkway.
Archibugiera	Louver (see) that allowed the firing of the blunderbuss.
arciera	Vertical slit to allow archery.
Arco	ancient military instrument, suitable for shooting arrows. It consisted of a piece of wood (more rarely in composite elements of metal or horn) that, forcefully bent by means of a string attached to both ends, could, by quickly and violently returning to its original condition, shoot an arrow embedded in the string.
Ariete	ancient impact instrument consisting of a large beam with a reinforced head, used to break through doorways or to breach walls. It also took the name of ram or cat (a diction adopted in particular to denote a beam mounted on a balance beam on a frame or rams with elements sliding on telescopic rollers within a movable castle).
armeria	weapons storage, usually in the castle dungeon.
Arpa	flying bridge with which walls and towers were climbed over or assaulted.
Arsenale	workshop in which ships as well as artillery or other weapons are prepared.
Artiglieria	definition encompassing all non-portable firearms (also called gun ports). Artillery is classified according to caliber (a name that used to denote the weight of the fired ball, and today the diameter in millimeters of the muzzle): small (up to 100 mm), medium (up to 210 mm), large (over 210 mm). Another classification uses as a parameter the length of the "core" of the barrel, measured in calibers. Thus we have: mortars (length less than 12 calibers), howitzers (12 to 23 calibers), cannons (over 23 calibers). Related to the length of the core is the type of shot (see): very curved, curved or stretched, respectively. On the combination of these characteristics depends the different use (offensive or defensive) of the various guns.

Name	Definition
Balestriera	horizontal slit that allowed the use of the crossbow.
Ballatoio	open corridor, usually cantilevered on stone or wooden corbels, much used in fortified architecture, at first only for functional purposes, later also with decorative intent.
Baluardo	masonry defensive appurtenance, pentagonal or heart-shaped, that replaced corner towers as a response to the appearance on battlefields of firearms and powder artillery. In current parlance it is synonymous with bastion (see), a term that has come to prevail, but which originally designated an earthen, not a masonry construction.
Barbican	advanced construction, often detached from the walls, intended to defend their bases; the term is often used as a synonym for ravelin (see), i.e., advanced work placed to protect the openings and gates of the city wall.
Barbetta	massive embankment on which firebows used, generally, for frontal firing (barb artillery) were installed in the open air. The name was derived from the fact that the artillery blaze "bearded" the embankment in front.
Bassa Corte (O Piazza D'armi)	fortified enclosure, sometimes of considerable size, attached to the castle proper and within which were housed lodgings, stables, storehouses, makeshift shelters. It served mainly, in case of danger, as a shelter for the population of the surrounding lands. When such an enclosure is reserved only for military functions it is referred to as a parade ground.
Bastia O Bastita O Bastida	advanced stronghold, semi-permanent in character, or even mobile, popularized in Italy by the French during the 13th century. It was used to fortify places on which it was not possible or convenient to build a permanent fortification, or to besiege a town: in this case as many bastides were set up as were needed to shelter all the besiegers. The name has since remained with numerous localities.
Bastionatura	defensive system based on bastion walls (see rampart and bastion front).
Bastion	defensive appurtenance adopted as a result of the advent of powder artillery, to reinforce the meeting point of two curtains and, at the same time, to allow effective flanking defense. It usually consisted of a vast masonry-clad embankment, pentagonal in plan (two faces, two flanks, one ravine), on axis with the bisector of the corner formed by two angled, adjacent curtains (see capital).
Batteria	Organic ensemble of multiple artillery pieces.
Battifolle	Mobile stronghold on the type of the bastia (see) placed to guard points of forced passage.
Battifredo, Battifreddo, O Belfredo	Formerly, wooden lookout tower, with bell to sound the alarm. Later, mobile siege tower, sometimes equipped with swinging ram (see elepoli).
Battiponte	strengthened end of the fixed bridge, made of masonry or wood, on which the end of the drawbridge was to rest (i.e., beat).
Beccatello	corbel supporting the parapet of the patrol walk when it was overhanging, as became customary in the late Middle Ages in castles of more developed architecture (the so-called projecting apparatus). Decorative effects were not infrequently sought in the corbels by using materials other than curtain walls, particularly dressed stone: the triple corbelled stone corbel is typical.
Bertesca	light wooden or masonry work, projecting from the line of the walls at the points of greatest defensive effort; in addition to easier sighting, it allowed a more concentrated plumb defense. Small bartizas equipped with loopholes were often used as guardhouses or sentry boxes in the corners of towers or buildings to allow good flanking defense as well.
Bicocca	small fortress or advanced defensive work, intended for sighting. In the past it also had a derogatory meaning, born of usually being a light or even improvised fortification at best, unsuitable for prolonged and effective defense.
bocca da fuoco:	name used to denote artillery pieces (see)
Bolzone	The term could indicate 1) a particular type of thunderbolt thrown with bolzoni crossbows; 2) a beam by means of which, with a particular system of winches, the drawbridge (see) was maneuvered, and which would fit into special grooves cut in the walls. Often the bolzoni seats are today the only visible trace of ancient fortified architecture.

Name	Definition
Bombarda	war machine with which, before the invention of firearms, stones, thunderbolts, and fires were thrown. After the invention of firearms, it became a generic name for any artillery.
Bombardi-era	first meant the compartment of the walls for which the shells of the bombards were thrown (see); then it indicated the embrasure for the cannon: in this second sense it was the primitive name by which that architectural detail later known as the gunnery or troniera (see) was referred to.
Braga	outer and low doubling of the walls of a fortification; it often constituted an added patrol walkway, serving as a lookout, antimine protection, and a platform for grazing fire. It was adopted especially in the early days of the use of firearms.
Breccia	Opening made by means of weapons in the walls of a fortress or city wall.
Briccola	device with which projectiles were thrown into besieged castles, before the invention of firearms. It corresponded to the ancient Roman catapult.
Brulotto	old, now decommissioned vessel that was hurled at enemy ships to sink them or at harbor fortifications to breach them.
Buca Di Lupo	obstacle and pitfall for the advancing enemy and consisting of a deep pit, with a narrower base in the bottom and a sharp stick planted in the center. Wolfmouths were usually dug in three or four rows, arranged in a checkerboard pattern, at the bottom of the fortification moat.
Buca Pontaia	hole with a round or square cross-section left in the structure of walls and towers for the purpose of serving for repairs, but especially to easily protrude occasional embedments or overhangs for defense.
Caditoia	Compartment made between the spouts (see) of the projecting apparatus. From this compartment stones, darts, or boiling water, oil, or pitch were plunged on the assailants.
Calastrelli	is the name given to the "thighs" of artillery shafts (see).
Calibro	Diameter of a gunport. It is usually expressed in millimeters (see artillery).
Camera Di Tiro	space cut into the thickness of the walls, toward the inside of the fortification, at a slit, gunnery, or gunnery and used for the movement of the servants of the weapon.
Camicia o Incamicia-tura	layer of coating of various types added on the outside of the embankments of a fortification for the purpose of cushioning the striking and penetrating power of incoming projectiles or consolidating the surface of the artifact against erosion or damage caused by weather and time.
Caminada o Caminadella	internal road, running along the walls of the castles in order to facilitate the movement of defenders from one point of the walls to another.
Camminam ento di Ronda; Corritora; Rondello	passage carved initially in the thickness of the walls, then by means of corbelling in overhang, immediately behind the breastplate or parapet (see), and which enabled the defenders to carry out constant internal and external control of the defensive circuit by means of regular passages of patrols (ronde). Through the machicolations (see) drilled in its projecting part it also served to make a lead defense (see) over the entire wall perimeter.
Campo Trincerato	area defended with mutually connected permanent fortifications, so that defenders could move under cover from one to the other, making use of trenches or covered walkways.
Cannoniera	large, angled embrasure made in casemate or barbette to allow for the use of a muzzle. Almost always the "trumpet" of the embrasure had a double splay (inner and outer) with anti-chipping roundings drilled into the side battlements. The portion of the front parapet that limited its plane was called a "toggle" because it provided valuable shelter for the gunners' knees.
Capannato	synonym for caponiera (see), when the building was located alongside and on the extension of the foot of the rampart.
Capitale	bisector of the corner formed by two adjacent and angled curtains, on the directrix of which the bastion is grafted (see)

Name	Definition
Caponiera	defensive work practiced inside the moat, to allow covered passage from the main enclosure to the outer defensive works: hence the name, derived from its function of "covering the head" of those passing through. Sometimes it had the functions of the casemate, allowing grazing fire over the moat. It often extended the foot of the rampart.
Caposaldo	tactical field element, which is part of fortified architecture when it has a permanent character. In this case it usually consists of a tower for sighting and signaling.
Carbonaia	ancient name for the holes that were drilled in front of the gates, across the moat, to provide an additional obstacle to attackers. The name may be justified by the assumption that coal was collected in such holes, which, when ignited, could constitute an obstacle that was difficult to surmount.
Casaforte	building equipped with certain fortifying features (e.g., narrow slit windows, elevated door, plumbholes on entrances, possibly battlements) and capable of containing a number of defenders capable of offering initial resistance to enemy assaults.
Casamatta	covered defensive appurtenance, carved out behind and inside walls and used for grazing defense; it was equipped with wide horizontal loopholes, so as to allow a wide sector of firing or a pre-determined section firing. Sometimes articulated, multi-pitch or multi-story casemates are also found: these types were used especially for the grazing defense of moats.
Cassero	name frequently attributed, especially in the regions of peninsular Italy, to the keep (see); synonym sometimes for tower with lookout and control functions (especially of a body of water).
Cavaliere	1) in medieval warfare parlance, it meant a war machine raised along the walls to launch darts inside the besieged castle or square; 2) by extension, any fortified work that is higher than another that is part of the same complex; 3) more narrowly, the works of this type that in the early days of bastion architecture were built on the axis of the ramparts or curtains with the intention of "commanding", with their fire, the ramparts or curtains themselves. They were gradually abandoned as their too prominent silhouette made them more dangerous than their dominant position made them useful.
Chiostro	architectural element peculiar to convents or monasteries but which was also adopted in castles, to gentrify the residential area. In this case it is more correct to refer to it as a courtyard (arcade or loggia) (see).
Cinta	defensive complex around a castle, walled land, or walled city. It could be simple (a single wall) or multiple (several walls, usually three, rarely five).
Circonval-lazione	continuous line or ditch erected by the besiegers outside their camp, i.e., toward the countryside, to prevent any relieving or resupplying action of the besieged by outside relief. In the age of rampart architecture (17th/18th century), provision was made to normalize its dimensions and characteristics: as a rule it was 7 feet deep, 12 feet wide and equipped with parapet and forts. Not to be confused with the countervalley (see), which was instead facing the besieged fortress.
Cisterna	essential element of castle logistics intended for the castle's water supply and consisting of a storage facility (usually masonry) in which rain or spring water was collected and stored.
Clavicola	masonry shelter (see rivellino), usually crescent-shaped, placed before the gates of the Roman castrum.
Contrafforte	wall with which the base of a fortification was strengthened to better support the thrust of the embankment behind it and at the same time to make it more resistant to artillery fire.

Name	Definition
Contro-guardia	in the rampart front, an external work of reinforcement and doubling the rampart; it had a V-shaped section with faces parallel (but lower) to those of the rampart.
Contromina	underground work made by the engineers of a besieged fortress to counter the enemy's mine works. A blast chamber may be obtained there, the blasting of which causes the ruin of the enemy mine.
Counterscarp	wall that closed the ditch on the country side, that is, on the side opposite the escarpment of the walls.
Controvallazione	continuous line arranged by the besieger between his camp and the besieged fortress to defend against possible sorties by the besieged. Not to be confused with circumvallation (see), which was instead the line of defense against attacks from the countryside.
Coprifaccia	Earthwork made for the defense of the faces of the ramparts.
Cordolo	architectural expedient adopted on the outside of parapets or battlements to prevent the sliding or ricocheting of projectiles launched from below.
Corno	work of reinforcing the weakest and most exposed points of a defensive complex: it usually rested on revetments (see) and formed a closed and advanced counter-guard (see). Because of its layout it was also called a priest's hat or swallowtail.
Corona	defensive complex similar to the horn (see), consisting of two or three rivulets linked together.
Corte	social element characteristic of castle life and consisting of the lord's retinue. Derived from the late Latin curtis, self-sufficient (and in the late Empire usually fortified) seigneurial agricultural residence, which was often (in France especially) the basis of the later feudal evolution of society.
Cortile	space within a building, enclosed within walls or building bodies. It often constituted the heart of the castle, and its vital disengagement area between the various sections. It was also often the most architecturally prestigious and elegantly decorated part.
Cortile D'armi	small courtyard carved out immediately after the castle entrance, where, with various devices, the impact of any assailants who managed to force their way in was contained. Entering the castle proper usually required passing through a second gate, offset or angled from the first and usually protected by fortifications on either side. Sometimes the courtyard of arms took the form of a gallery or coming-and-going gallery, i.e., angled, with machicolations in the vault, loopholes on the sides, and with pitfalls in the planting. The courtyard of arms was also used to organize possible counteroffensive sorties. The name was later also given to the inner courtyard where garrison exercises were held.
Curtain (wall)	Part of the wall between two successive towers or bastions. Essential element of any fortification, as it establishes the perimeter that must be defended.
Corvée	originally, personal service required by the feudal lord from his serfs, particularly for the construction of fortifications; it later indicated, by extension, personnel assigned to cleaning inside the castle and, later, the barracks.
Dardo	Arrow with enlarged tip in two sharp sides.
Defilamento	expedient typical of fortified architecture consisting of hiding from view or evading the enemy's blows a building, or anything that might attract his attention, by covering it with an appropriate shelter.
Dente Di Sega	1) defensive system, already used in prehistoric times, consisting of shaping in plan the walls of a fortification according to a series of indentations and salients. This was done to prevent so-called enfilade firing (see) by attackers and to allow, on the contrary, easy flanking defense action (see) by the besieged; 2) decoration of a wall surface, usually in brick, typical of late medieval castles in some parts of Italy (particularly Piedmont, Liguria and Lombardy) and consisting of successive bands of bricks arranged to form a serrated pattern.
Diateichi-sma	inner walls of a fortress erected for the purpose of creating a compartmentalization of the defensive complex, so that in case of failure of a part of the defenses the front could be contracted by abandoning only the portion forced by the enemy and continue resistance in the remaining portion.

Name	**Definition**
Difesa Attiva	Any defensive method that opposes the enemy assault not by waiting for it behind the walls, but by countering it during the approach and at the time of the assault
Difesa Fiancheg-giante	method of defense aimed at defending a fortification by flanking (see), that is, by an enfilade shot that would catch the attackers in the flank. To achieve this, towers were built projecting from the edge of the walls so that shots could be made parallel to the curtains.
Difesa Manovrata	consists of moving a core of defenders from one part of the defensive front to another, concentrating them where they are most needed. In order to implement it effectively, it was essential to have fast communications between the various parts of the fortification, by means of continuous patrol paths or covered tunnels connecting the various defensive works.
Difesa Passiva	is one that relies solely on the protection afforded by distance, inaccessibility and the thickness of fortifications, without countering the enemy.
Difesa Piombante	defensive tactic typical in the white-weapons era, based essentially on throwing solid or liquid projectiles (stones, or boiling water, oil, pitch, or sand) at attackers. To implement it, it was essential to have an elevated position relative to the enemy, achieved by choosing a naturally high place or by elevating oneself from the ground through architectural artifacts (walls, towers).
Difesa Radente	typical defense implemented with the use of firearms, by means of shots as close to or parallel to the plane of attack (see) or plane of country (see) as possible, that is, by employing weapons with what is called "zero elevation."
Dongione	Frenchism (from "donjon", in turn from the Latin "dominium", pronounced in the French manner, "dominiòm") for mastio (see). However, it is used with a different shade of meaning: in fact, it indicates (particularly in Piemonte or Lombardia) a castle consisting of a large tower containing the functions of dwelling, defence and storage typical of a castle (Serralunga d'Alba, Carbonara Scrivia).
Esostro	bridge located on the second floor of the assault towers, by means of which attackers could storm the walls at the height of the battlements.
Faccia	constituent part of the bastion.
Falarica	long spear that was thrown over the walls, by hand or with ballistae, to cause fires inside the castle, as working fires were set at its end.
Falcone Falconetto	gunners of the 16th century that differed in power. The former threw iron balls of 6-9 pounds, the latter balls of 3-4 pounds. F. was also called "mezzo sagro".
Fascinata	quantity of bundles piled in bulk or tied in bundles that were used to make shelters (trenches) or to fill in ditches.
Feritoia	slit cut in the walls in order to target assailants without exposing themselves. Depending on its specific use, it was called an archer, crossbow and arquebusier, but there were also composite slits that allowed the use of two or three different weapons.
Fiancheggia-mento	shot made along the outer edge of the walls in such a way as to hit from the flank anyone attempting to assault the castle, with obviously more effective results than the frontal shot. It marked an evolution in defensive systems.
Fianco	constituent part of the bastion
Ficcante	shot made from above on an assailant. It contrasted with the grazing shot, which was less effective.
Finestra	non-existent, or almost non-existent, in the oldest feudal castles, it was adopted, but only towards the inner courtyards, in later times, until with the castles of Lords and Princes, it became an architectural motif of pre-eminent aesthetic importance.
Forte	solidly fortified and exclusively defensive (not residential) building; it began to be built from the 18th century onwards, away from towns, to dominate valleys, important routes, or as a stronghold of pre-established lines of resistance.
Fossato or Fosso	canal dug around a castle or fortification, between the scarp and the counter scarp, to increase its defensive possibilities. There could be an open f., visible f., or a flooded f., or a dry f., or a flooded f., or a f. with water, and even a blind f., covered by reeds or faggots.

Name	Definition
Freccia	1- see lunetta 2 - projectile consisting of an iron-tipped rod with a finned tail (to better guide its trajectory), which was thrown with a bow. It was distinguished in strade, versetto, quadrello, dardo (see).
Fronte Bastionato	defensive system based on city ramparts.
Fronte Bastionato Italiano	bastioned front, made in Italy.
Fronte Bastionato Italiano Migliorato	bastion criterion according to the «Addizionale Erculea» of Ferrara, designed by B. Rossetti in 1497.
Fronte Lineare Continuo	is the designation of large lines of fortifications also adopted recently. (Linea Maginot, Linea Sigfrido, Linea Gotica, etc.).
Fronte Tenagliato	defensive system devised by Landsberg (1670-1746).
Fustigata	central gully carved into the bottom of the ditches to allow for a water economy in peacetime.
Gabbia	wooden watchtower
Gabbionata	expeditionary trench made with gabions (later with bags) filled with earth or stones.
Gabbione	bottomless cylinder of rushes or wire mesh, which, filled with earth or stones, was used to make trenches or gabions.
Galleria	underground or covered conduit, to place mines or to detect tunnels made by the enemy, or to allow a safe and secret transfer from one sector to another of the defensive front. The g. was a customary architectural element in castles, for entrances, walkways. accesses to crossbows or archers, to ensure the flow of armour at crucial points of defence.
Gancio	placed at the end of a rope was a launching tool to enable an individual to climb a wall.
Garetta O Garitta	bertisca protruding from the walls, for sighting or for combat from above, with white weapons. Then turret placed at the salient corners of the fortifications. Finally, a shelter post for sentries.
Gola	pass through which one accessed the bastion or tower of the defence complex. For this reason, the g. was mostly open, i.e. empty, precisely to allow easy passage of men and materials. Gorge of the strut 15th century.
Guardiola	protruding bartizan for sighting or fighting from above. (see "garetta o garitta")
Linea Di Difesa	alignment of fortifications erected to defend a front; or, in ancient times, criterion adopted for the construction of a defensive system.
Linea Trincerata	linear defensive preparation, typical of positional warfare; but it can also be a dispatchable preparation.
Lizza	land between two successive city walls (usually between the second and third). When it remained free of superstructures, it was used for tournaments and competitions. Hence the saying «going down to lizza».
Lucchetta	wooden shelter that was placed between the battlement and battlement to cover the lurking marksman. See also "mantelletta".
Lunetta	additional work in the bastionated defence system: it was inserted as a second rearguard beyond the rampart, often with a doubling of a covered road. It served as an outpost or to augment the flanking action of the besieged; it was also called freccia (see).
Magistrale	main or primary wall, in the multiple walls. The presumable directrix of the enemy's attack was then indicated, taking it from the axis of symmetry passing through the middle of a curtain wall from the parade ground.
Keep	the highest and most central part of the castle, usually consisting of a sturdy tower.

Name	Definition
Merlatura	set of battlements on towers or walls.
Merlo	masonry expedient of the upper parts of castle walls and towers.It consisted of a symmetrical break in the wall, behind which the shooter would take cover to deflect from the adversary's reaction. Different styles were adopted depending on the location: triple-toothed, flower, pyramid, semicircle (hence the ensemble of battlements was also called trine, lace, prominence). In the earliest feudal castles, the battlements were built flush with the outer wall; later they were built on projecting walls, to allow for a more effective lead defence. They were also built tapered, double-sloping; with kerbs or comici to prevent arrows or arrows from slipping through; with slits.
Merlone	parapet between two thrones or gunboats. It was distinguished from the battlement by its thickness and by being rounded so as not to allow easy impact by enemy artillery shells. It was also called nut and melon.
Mezzaluna	in the 15th century it consisted of a ravelin with a semicircular plan. In the 16th century, a triangular ravelin towards the enemy, semicircular towards the interior; then it came to mean a ravelin (triangular or otherwise) placed before the curtain in the rampart system.
Mina	ossidional technique characterised by the digging of a tunnel (mine tunnel) in order to create a cavity under enemy fortifications.The tunnel was shored up to support the weight of the fortifications above. Once completed, the cavity was filled with incendiary or explosive material and fire was applied, resulting in the collapse of the walls. Sometimes the tunnel would continue to be dug, beyond the defensive curtains, in order to penetrate inside the stronghold with the aim of opening the gates to the besieging army ready to attack.This technique was widely used to the extent that 'counter-mine' techniques were developed to search enemy tunnels. Soon, with the spread of the bastion front, fortresses were equipped with 'counter-mine' tunnels. organised on various levels and distances, in order to also counter oxydian artillery batteries.
Mortaio	artillery characterised by a curved shot and the limited length of the barrel, which, inclined at an angle generally greater than 45°, makes it possible to reach targets that cannot be hit by the fire of direct-fire artillery pieces, as they are placed behind vertical obstacles.The M. is generally used for the firing of explosive projectiles at low velocity.
Moschetto	the term indicates the largest and most powerful portable firearm, derived from the 'blowpipe', in use between the end of the 15th century and the end of the 18th century. The M. was equipped with various ignition mechanisms, but the most popular one due to its inexpensiveness was certainly the 'fuse' mechanism. Most of these weapons were equipped with a fork to support their weight during aiming and firing.There were also larger types of M., called "carabiners", "double muskets"and "pushers", used on ships and on the battlements of fortifications.The term M. was also used for tinder guns or modern ordinary repeating rifles.
Motta	a mound, natural or artificial, surmounted by an enclosure, a palisade or a more complex fortification (usually a tower), typical of Norman fortified architecture.
Mura	constituent element of the castle and fortified walls. The primitive simple walls were followed by multiple and complex walls.
Murata	noun adjective to indicate the citadel or keep of a fortress.
Musculo O Muscolo	small war machine that served to keep those who filled the ditches around the castles with earth, stones or bundles out of harm's way.
Orecchione	Embankment added on the outside of the rampart to better cover the flank. Rounded chamfer of the angle between the flank and face of the rampart. It served to cover the embrasures of the flank, which was, in this case, «withdrawn».
Palandra E Bombarda	cast mortar with base and installed on ships, particularly suitable for bombarding cities from the sea.
Parapetto	outer wall of the patrol walkway, through which the patrolling soldiers had shelter. The battlements were raised on the parapetto.

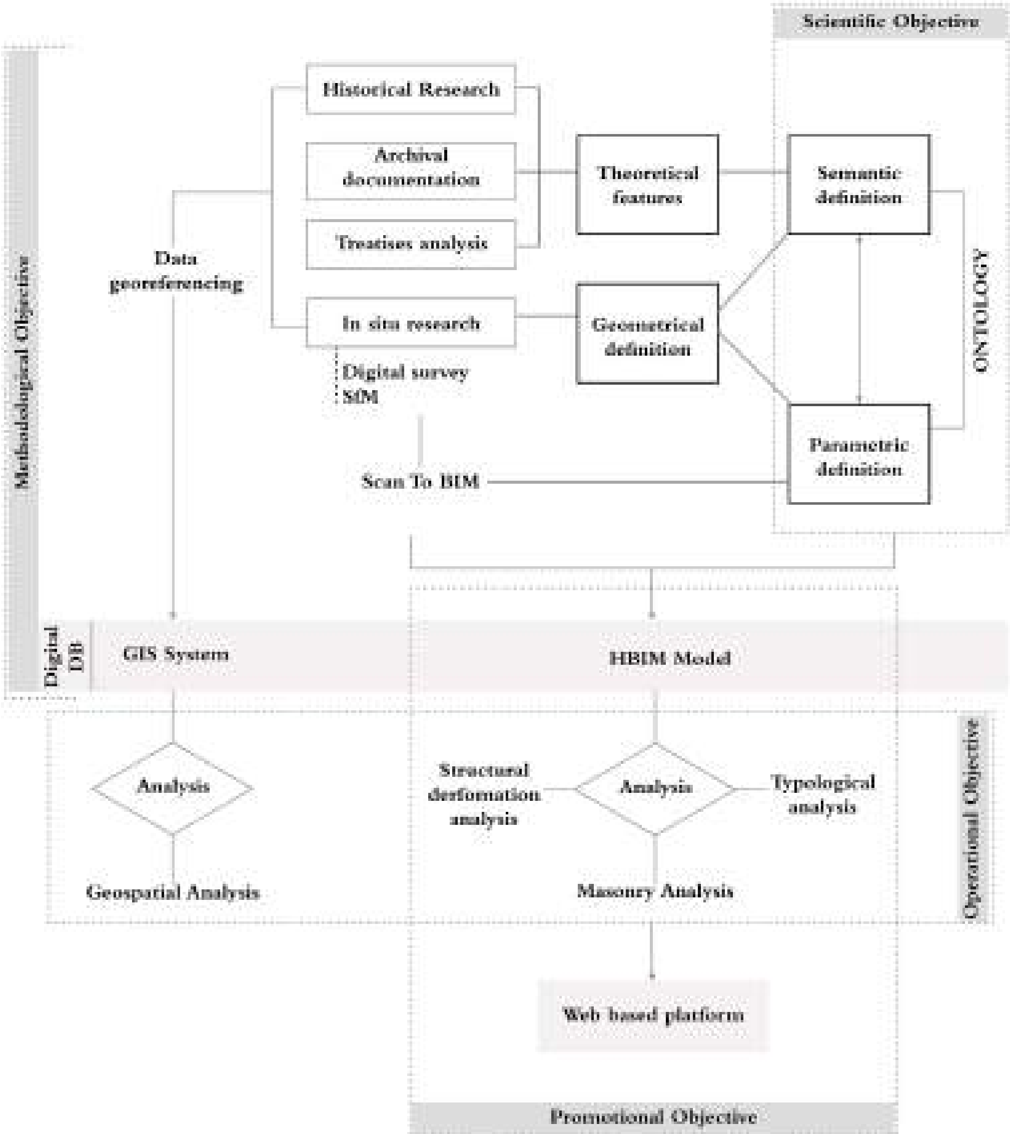
Name	Definition
Piazza O Piazzaforte	in military jargon is a generic term for a fortified place.
Piazzamola	embankment on which a particularly heavy weapon (artillery) was placed.
Pignatta	container filled with tar or something else that was used to light ditches and walls at night in order to prevent sudden assaults by enemies.
Piombante	(throw) synonym for ficcante (see)
Piombatoie	pivotal element of the protruding apparatus, i.e. that ledge at the top of the curtain which allowed projectiles of all kinds to fall through special holes (piombature, in fact), by gravity, onto the head of the enemy below.
Plueo	ancient machine with which one approached, under cover, the opposing walls.
Ponte Levatoio	movable bridge designed to provide greater security at the entrance to a castle or fortification. Hinged, it was raised with a system of beams, called bolzoni, to form an airtight portal. Various systems were used to raise the l.p.: stairway, self-balancing, constant, lowered, double bridge, multiple device, double safety.
Puntone	tower projecting from the edge of the walls. It was mostly pentagonal and marked the transition between tower and rampart. In the 15th century, it already had the character of a bastion.
Pusterla	diminutive of porta. In fact, it was a pedestrian opening along the walls or alongside the carriage drawbridge. In this case, the p. was also equipped with a drawbridge of adequate size and operated by a single bolzone with a forcola.
Quadrello	arrow with four-pointed tip.
Radente	tensioned shot made, as far as possible, at ground level.
Ramparo	is the height of the earth constituting the foundation of an entire fortification.
Recinto	synonym of mura and cinta (see)
Ricetto	grouping of houses, also surrounded by towers and walls, usually in the plains, in which the helpless population scattered across the countryside found refuge during calamities or wars.
Ridotto	small fortification or stronghold in which the combatants gathered. For Vauban, it was a small citadel. Depending on its configuration it was called: open r., closed r., large r., casemate r., sawtooth r., crescent r..
Ravelin	Robust, additional, advanced fortified work, shaped in a V or rectangle or semicircle, in front of a gate. It had its own moat and was also used for flanking fire. It was often connected to the trench or to the curtain wall behind with a gallery. External work built outside the main curtain wall, shaped in a V or semicircle, to cover weak or exposed points (e.g. the head of a bridge). Some, especially the medieval ones, have square, rectangular or round shapes. They often have their own defensive moat, connected to the main one.
Rondella	small round bastion, mostly angular.
Saettiera	slit particularly suitable for the use of crossbows and, therefore, for throwing lightning bolts from the roof.
Saliente	defensive line that pushes at an angle towards the enemy. The bastion, pointed, has a «salient» along its capital line.
Saracinesca	wooden or iron door or gate placed at the entrance to the castle or fortification, in addition to the outer gate. It usually dropped down along special grooves, also to quickly block any enemy infiltration. In this case it closed off the small piazza d'armi (see) of the entrance.
Scala	customary architectural element in castles and fortifications. Fixed and movable, built into the thickness of the walls or projecting, in tunnels or open galleries, they initially obeyed functional criteria; later they also obeyed aesthetic, representational criteria (scaIons).
Scarpa	moat wall along the walls or inclined wall addition at the base of the walls, to strengthen them and eliminate the dead angles in front of them, to prevent the approach of mobile towers and the danger of mines.

Name	Definition
Spacciafosso	firearm (artillery) particularly suitable for striking enemies who have penetrated the moat.
Spalto	An embankment sloping towards the enemy, protecting a road covered with a counterscarp, interspersed with gun emplacements and shaped like a sawtooth to prevent firing. It was also equipped with open, underground ladders to allow for sorties. There were fortifications with double ramparts.
Spezzamento	when, for topographical or tactical reasons, a line of defence was interrupted. It was generally adopted at mid-curtain, whereby the s. of the curtain was the withdrawn flank of the line of defence.
Tenaglia	defensive work consisting of faces forming a convex angle. In the bastioned front it consisted of a low antemurale, with the task of increasing the defence of the moat or covering a pusterla. The t. could be simple, compound, double, broken.
Tenagliato	fortification system designed by Montalembert, with a star-shaped plan.
Terra Murata	walled communal town, with towers and moat, and with architectural and defensive devices that were often more advanced than in feudal castles.
Terrapieno O Terraglio O Terraggio	earthen or encased elevation on which heavy weapons (artillery) were placed. It could have two levels: the lower, more sheltered part served as a reserve and to facilitate connections.
Terrazzani	the inhabitants and defenders of a walled land.
Tiro	The act by which, either by hand or with a mechanical device (firearm), a projectile is launched. Depending on the trajectory, one has t. taut and t. short, t. long and also t. smear, t. ricochet.
Tollenone	ancient assault weapon. (see "altaleno").
Torre	first erected only as a lookout and signalling tower, then as an integral element of the castle (not to be confused with the keep), reinforcing the walls (angular t.) or defending the entrance. It had a quadrilateral, circumcircular, polygonal, semicircular, elongated plan, with parallel vertical walls and open at the rear. Defensive weapons were installed and used for plumbed defence. They were rarely built with beak or almond-shaped spurs. Instead, they were almost always equipped with pikes, crossbows or other loopholes. In noble times, towers were built with overlapping geometric elements of the same or different species (cylindrical base and parallelepiped t., or vice versa). Depending on their function, there was a lookout tower, a coastal tower (also known as a Saracen tower) or a hammer tower.
Trabocchetto	door in the floor, held in such a way that only when passing over it would fall, causing the unfortunate person to fall into a pit bristling with blades or other contrivances designed to catch or kill him. Pitfalls were usually placed at the entrance, but also, sometimes, inside the castle.
Traditora	battery concealed in a barbette or just exposed in such a way that it was not visible to anyone assaulting on the masterful defences. The term was also used for artillery set up for flanking fire, capable of beating anyone who approached the face of the rampart or moat.
Traversa	mostly earthen construction, with which they prevented shooting in the straight sections of the defence.
Trincea	the simplest and sometimes the only defensive arrangement, consisting of a ditch with an embryonic parapet or a wall made of sacks, bundles, gabions. It once constituted an approach line, ahead of more solid defences, in which the defenders then took shelter. It had a non-rectilinear layout, to prevent shots being fired, and often branched off into walkways. From the prevalent use of this albeit embryonic system of defence, «trench warfare» took its name, as a synonym for positional warfare.
Troniera	synonym of cannoniera (see)
Zoccolo	walling device to prevent siege machines from approaching the walls.

IV

ONTOLOGY SEMANTIC DATABASE PARAMETRIC MODELING

Ontology-based semantic database procedure for Parametric modelling of complex architectures



I. Procedure

The detailed study presented in this reaserch follows an established procedure outlined in this chapter. The general research presented in previous chapter provides the context and foundation for further steps aimed at understanding, preserving, and sharing the fortification heritage of the lower Lazio region. The study of treatises and military dictionaries was essential in creating a critical and comprehensive glossary, a robust tool that guides the construction of the ontology for the development of three-dimensional HBIM information models. The procedure here is outlined in detail because, although the study primarily focuses on five specific italian case studies (see chapter sV,VI), it can be universally applied to similar situations in different European regions.

Preservation and enhancement at the territorial level-in this case, the network of fortification structures-require a deeper understanding in their historical context. According to Villa (2015), such understanding has to go beyond military-defensive history and architectural language and must touch on the interrelationship between the structure and the surroundings, the urban context, and the physical elements that make up the whole of cultural heritage. As previously stated, military architecture has a wide scope in its study. This subject matter can only be understood through a critical review of the existing literature. This shall involve an in-depth analysis evidences from treatises. One of the important features that come to light from these various literatures is forming a relation among the different parts so as to ultimately achieve the purpose of forming a separate and independent item. Knowledge acquired, together with historical-archive data, forms the basis for developing the ontology of fortified architecture. This is based on semantic definition related to the historic fortresses that are presently in a state of neglect. Thus, developed ontology forms the basis for constructing integrated information models that shall raise awareness of the conditions related to the architectural structures of interest.

In the previous page: Fig. 1 Procedure diagram with key steps for achieving research objectives. (Author's elaboration)

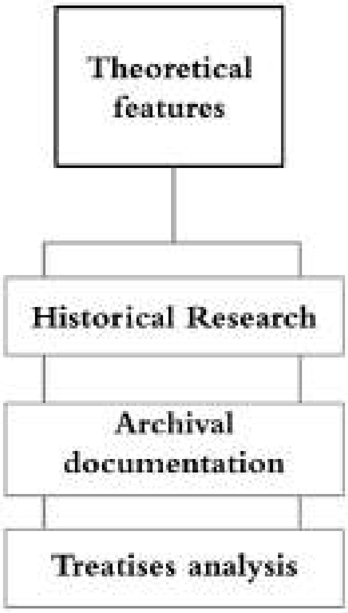
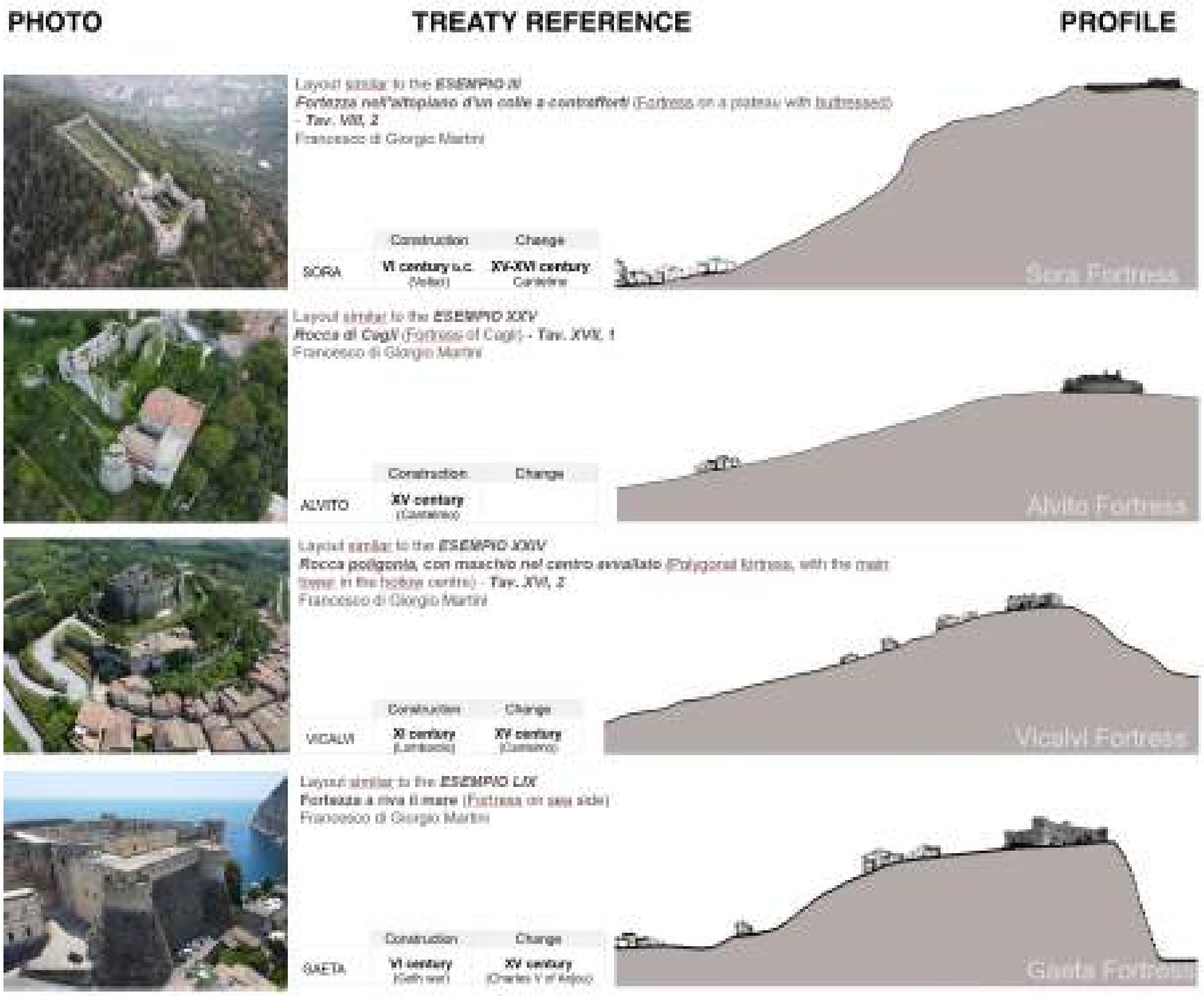


Fig.2 Diagram detail: Theoretical features Author's elaboration)

1. Theoretical features - Data acquisition for the semantic definition of fortified architecture

The initial phase of acquiring essential knowledge begins with a comprehensive and in-depth historical analysis and investigation. This includes referring to historical sources and archival documents to reconstruct the development of the fortified architectural heritage. These efforts must be complemented by on-site surveys and measurements using modern instruments and technologies. As such, the first phase of knowledge acquisition, data collection, and awareness is crucial. The information gathered forms the basis for conducting diagnostic analyses on the architectural object, as well as identifying and defining the necessary recovery interventions to be implemented, and planning subsequent maintenance activities. The sources for the ontological analysis of defensive architecture are the treatises of military architecture and the dictionaries, respectively for this specific study Bonaiuto Lorini's for the book of history of evolution of fortified architecture, and Francesco di Giorgio Martini, as he writes during that delicate period called "transition period" in which the fortified archiecture analysed in this study underwent massive modifications. For the particular cases of study, that will be further shown in detail in the next chapter, it was possibile to link Francesco di Giorgio Martini consideration with the consistencies of the fortification analysed (Fig.3)

Fig.3 Correspondance between fortresses selected for the application of the procedure and Francesco di Giorgio Martini's examples (Elaboration by the author)



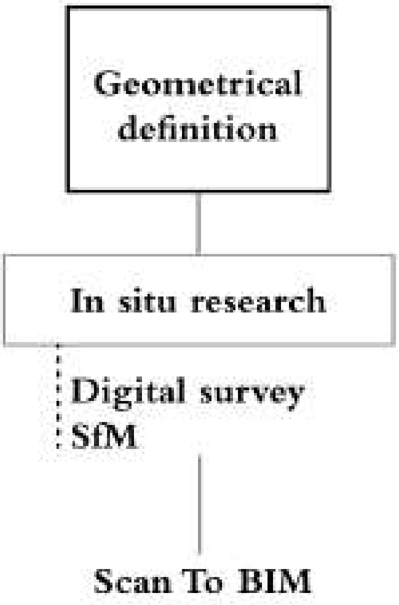


Fig.4 Diagram detail: Geometrical features and digital techniques. (Author's elaboration)

2. Geometrical features - Digital techniques for the parametric definion of fortified architecture

When creating an ontology for architectural heritage, it is important to establish a structured framework that formally defines the relationships between concepts and elements. This framework should not only include theoretical features, but also define the geometrical parameters describing the architectural heritage. The goal is to develop a comprehensive and standardized vocabulary that can effectively describe and manage the complex information related to fortified heritage, their components, and their conservation processes.

All these components are collected in spatial (GIS) and architectural (HBIM) databases. The HBIM methodology utilizes various technologies for collecting data and information. These include photogrammetry and laser scanner surveying, which enable the association of geometric information with images to create a highly accurate virtual model. By employing laser scanner and photogrammetry, and subsequent data processing that involves georeferenced coordinates, a point cloud can be created. This point cloud provides the basis for modeling the object, defining its volumetrics, dimensions, and color information. The survey data processing also allows for the creation of meshes from the point cloud, leading to the initial development of a 3D model. The final step involves digitizing and creating a three-dimensional, parametric, reality-based BIM model.

For this study the geometrical data are acquired with an established survey project. The comprehensive survey project aims to recognize the historical authenticity of the monument's components, from the original layout to the present, also highlighting any superfetations. The survey project, in accordance with the indications of the Krakow Charter (2000), includes: an in-depth historical/documentary analysis, to identify the historical, artistic and socio-cultural significance of the monument; graphic and dimensional surveys, to facilitate the reading of the wall composition, the exact geometry of the lacuna and their interrelation; and assessments of the state of conservation, to determine the most correct indications for the partial reconstruction of the structural elements, so as to return the monument to the community in terms of usability. The geometric survey required the use of modern digital technologies, aerial drone photogrammetry, thanks to which it is possible to quickly obtain a metrically and geometrically reliable 3D model of the monument, capable of documenting even the most important pathologies of degradation, allowing digitally assisted visual examination.

Gathering accurate data about existing buildings is essential for conducting analyses. Architectural surveying has evolved into two complementary procedures: direct and instrumental (indirect) surveying [Docci & Maestri, 1984]. Direct surveying uses simple and inexpensive tools, while instrumental surveying relies on advanced technologies such as total stations, laser distance meters, GPS, and computer software [Bini & Bertocci, 2012].

Surveying involves creating interpretative models based on specific categories like shape, geometry, and position, and the direct method is typically used for smaller, simpler spaces and architectural details. In cases where buildings are located in difficult-to-access areas, such as the ones presented in this research, it is necessary to use instrumental, photogrammetric methods to survey height differences, large distances, and inaccessible points.

Aerial digital photogrammetric survey with drone

3D digital surveying techniques, such as laser scanning or digital photogrammetry, are now a real advantage for managing the complexity of architectural heritage at different levels of detail and scales of representation. As widely acknowledged, using SfM techniques allows obtaining detailed information about architectural objects by returning reliable geometric models on which to perform various analyses. In addition, UAV tools can also detect architectural objects that would take a long time with a traditional approach, thanks to the possibility of reaching places that are difficult to access (Saccucci et al., 2022). Based on measurement through light, photogrammetry analyses pairs of stereometric photographs so that the photographed object's shape, position, and dimensions can be detected using artificial stereoscopy. With the introduction of digital and computer algorithms capable of analysing photographs taken by a digital camera, it is no longer necessary to resort to metric cameras. The most famous algorithm is Scale-Invariant Feature Transform (SIFT), which is mainly used in Computer Vision (CV) to detect and describe the features of an image.

"Automatic digital photogrammetry" allows the creation of a three-dimensional model from digital photographs and enables the generation of point clouds (dense clouds) in x, y, and z coordinates. The term "automatic photogrammetry" has been recently introduced in specialist literature. Until recently, traditional photogrammetry was distinguished from automatic processing techniques, which were referred to as photomodeling (Brusaporci, 2010). The term Image-Based Modeling and Rendering is commonly used in English scientific literature, alongside the term automatic photogrammetry. Structure-from-motion is also used, although this refers only to the first part of the image-processing workflow (image matching and sparse reconstruction) (Bolognesi, 2016). For CV algorithms to identify homologous features (i.e., characteristics), the same object must be captured in multiple images from different positions. Typically, vertical photos should ensure at least 60% overlap between successive images and 20% lateral overlap between flight strips, with the same scale and preferably the same tone (Paris, 2012). In the case of aerial photogrammetry, many applications compatible with mobile devices used to pilot drones can set up automatic flight paths and waypoints (reference points) for the drone (Inflight). The area to be surveyed is identified, and the app calculates flight lines and shooting frequency to ensure the correct level of image overlap (Pelliccio et al., 2017). Moreover, as highlighted by the Restoration Charters, in the process of enhancing a cultural asset, the analysis and understanding of the close relationship between the architectural object and the surrounding landscape are fundamental to defining its main characteristics. For this purpose, drone aerial photogrammetry is highly beneficial, as it allows the investigation and modelling of the landscape, of which the architectural object is an integral part (Saccucci et al., 2022).

Software for IBM - Image based modeling

Agisoft Metashape is one of the most widely used digital photogrammetry software based on SfM (Structure from Motion) algorithms. It can process RGB or multispectral images, including multicamera systems, and convert them into high-technical spatial information such as:

1. Dense point clouds
2. Textured polygonal models
3. Georeferenced orthomosaics
4. DSM/DTM

The term Digital Elevation Model (DEM) refers to the "digital cartographic representation of terrain elevation at regularly spaced intervals in the x and y directions, using z values referenced to a common vertical datum" . The Digital Surface Model (DSM) represents the Earth's surface, including all natural and anthropogenic objects (buildings, trees, power lines, etc.), making it more suitable for 3D modeling, telecommunications management, or forest management . These 3D elevation models can be referenced to either the mathematical ellipsoid surface, showing ellipsoid heights, or the geoid surface, showing the elevations of each point.

Camera calibration is the first necessary step to process images. Modern photogrammetry software can calculate calibration parameters extracted from the image's "EXIF" file, which contains information about the camera model, sensor dimensions [mm], and focal length [mm]. The calibration model implemented in the software is of the parametric type with central projection and nonlinear distortions.
In this step, image processing software based on Structure from Motion (SfM) algorithms is used to generate georeferenced 3D models of areas acquired from aerial surveys. These software tools follow a standard procedure consisting of:

1. Loading the image dataset.
2. Image alignment. Depending on the project's reference system, the software calculates both the internal and external orientation of the frames: the GPS data usually present in the image metadata provides the necessary information about the flight plan and capture points.
3. Image optimization and camera calibration.
4. Creation of the dense point cloud. Structure from Motion algorithms use an image matching approach to search for pixel-to-pixel correspondences within an image pair. The construction of these correspondences and the calculation of 3D coordinates are based on the collinearity approach, assigning a relative depth value to each image pixel. The result is the creation of the "dense point cloud": the point cloud in the object space .

From the generation of the point cloud, it is possible to generate products such as digital elevation models (DTM/DSM).

Image Alignment:
Image alignment is performed by selecting processing accuracy. The duration of the alignment depends on the number and type of frames to be processed. Once the operation is complete, the set of aligned images is represented as a dense mesh of appropriately oriented blue parallelograms. The normals to each parallelogram, indicated by a black

segment, represent the orientation of each frame, which, combined with the others, leads to the creation of a sparse point cloud. The sparse point cloud is the first raw level of 3D model creation.
Metashape allows for the creation of a dense point cloud based on the internal and external orientation parameters calculated from the images. Dense cloud generation is based on depth maps calculated for overlapping image pairs considering their estimated relative external and internal orientation parameters through a "bundle" adjustment. Multiple depth map pairs generated for each camera are combined into a single depth map using the excess information in regions of high overlap to filter erroneous depth measurements. Combined depth maps generated for each camera are transformed into partial dense point clouds, which are then merged into a final dense point cloud with additional noise filtering applied in overlapping areas. In Metashape, the DEM can be rasterized from the dense point cloud, sparse point cloud, polygonal model (mesh), or generated directly from the depth map. The software can create both the digital surface model (DSM) and the digital terrain model (DTM). The latter can only be built using data derived from the dense point cloud, which should be classified into ground points and other semantic classes before the DTM generation phase . Once the dense cloud generation step is completed, the DEM can be generated with the desired parameters.
Ortho-mosaic Creation:
The ortho-mosaic is a combined image created by seamlessly merging the original images projected onto the object's surface and transformed into a selected projection (geographic, planar, or cylindrical). The planar projection allows the arbitrary orientation of the projection plane, useful for projects involving facades or other non-horizontal surfaces. A cylindrical projection can be used to minimize distortions for cylindrical objects. The geographic projection is used for the typical task of creating an ortho-mosaic in a geographic coordinate system. From the DEM obtained in the previous step, the orthorectified mosaic of the reference dataset is derived.

Other Products from Dense Point Clouds:
Other products obtainable from the dense point cloud include the Tiled model, wich allows reactive visualization of large and high-resolution 3D models. The tiled model can be built based on dense point clouds, mesh, or depth maps.

3. Digital territorial database: the representation of the phenomenon in GIS

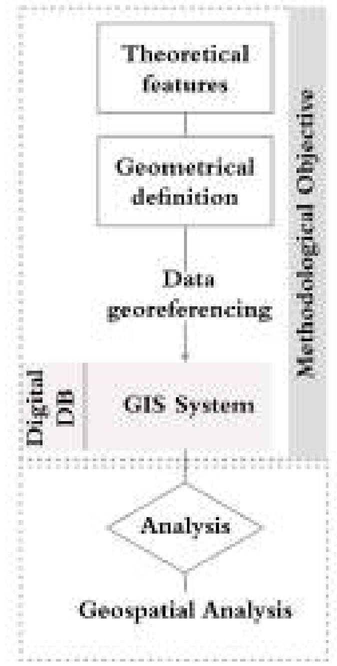


Fig.5 Procedure detail: digital territorial database and possible analysis (Author's elaboration)

As previously stated, all the fortications studied in this resarch are collected in spatial (GIS) and architectural (HBIM) databases. The GIS (Geographic Information System) is an indispensable tool. The georeferenced information system, composed of a set of computer tools, allows for the collection, storage, management, and distribution of information useful for the management and organization of the territory.
The cartographic base and database enable the digital representation of the reality of fortresses, their typological distribution, elevation, and so on. All information from site investigations and surveys is stored within it, allowing for organization and querying for subsequent analyses. GIS allows objects to be described in terms of their position relative to a known reference system, defines attributes that describe the characteristics of the object, and describes spatial relationships with other objects. Geospatial information, combined with analyses involving hazard, vulnerability, and exposure, represents a method of understanding the consistency and conservation status of built structures across the national territory. Together with GIS, BIM methodologies for the representation, production, and management of the built environment provide the possibility of integrating all documentation and knowledge aimed at conservation and enhancement.
The scale of the areas to be regenerated, their location, and contextualization require the acquisition of a multitude of alphanumeric, cartographic, and iconographic data that can interact to extract cross-referenced information useful for the most appropriate design choices. For this purpose, GIS, a tool for the representation and management of survey data, is currently the best system to meet these needs. Using this system, a map of the consistency of fortifications' typology and state of conservation has been designed for this study. It represents also a crucial instrument to understand the relationships between different fortfied architecture and read the interconnections present among the various fortresses.
Therefore, the GIS map georeferences in UTM WGS 84 different thematic maps readable in overlay, as a basis for conducting geospatial analyses, such as influence radii. On this cartographic base, municipal perimeters, boundaries extrapolated from historical cartography, and different types of fortresses have been acquired/vectorized from the general to the particular, each associated with a detailed sheet.

Each element is assigned a specific graphic symbol, shapefile, point, linear or area-based, depending on the object to be represented, listed in the Table of Contents. Through this, a link is created with the internal database of the information system, designed in compliance with national standards and ISO 19111 and ISO TC 211 norms. For each site, the database is organized into different sections: general - site name, location, year of foundation, type of ownership (public or private); historical - description of events characterizing the site, successive owners, iconographic material; technological - dimensions of the area, built volume, construction type, foundation type; conservation status; legislative - set of landscape and urban planning regulations in force on the area. Through queries, it is possible to visualize on the map all these technical/legislative and economic/social information, both on a broader territorial scale and within the municipal area alone, in the form of tables and graphs or simply as a planimetric representation (figure).

4. Ontology - Semantic and parametric definition

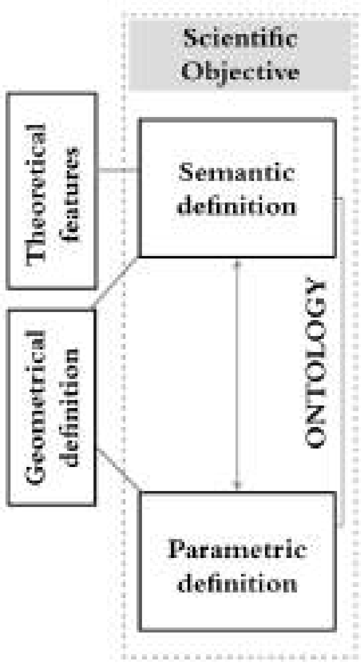
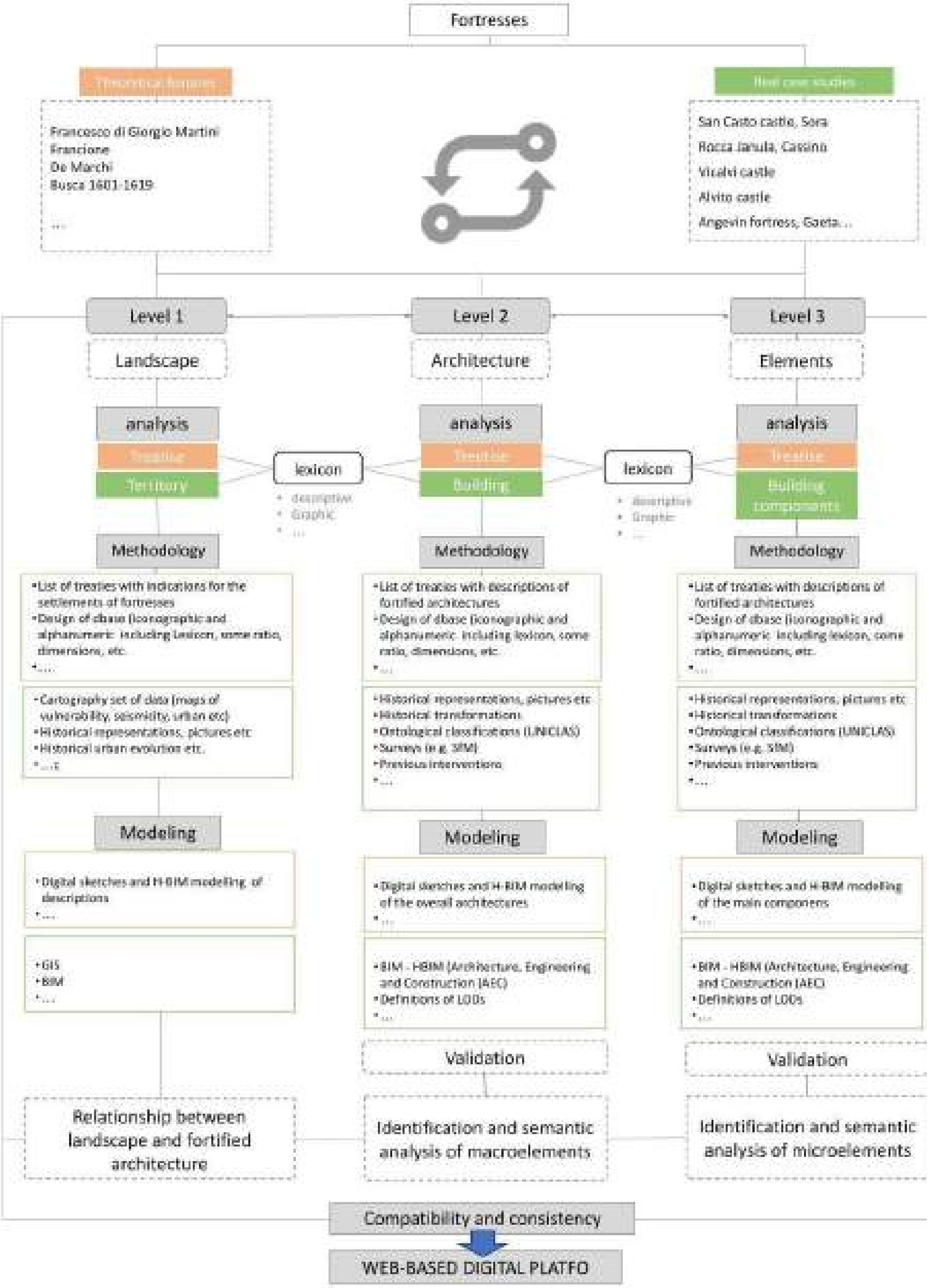


Fig.6 Detail procedure highliting the steps for achieving the scientific objective (Author's elaboration)

In the context of architectural heritage, an ontology can include various elements such as building types, materials, construction techniques, historical periods, and conservation practices. The goal is to provide a coherent and interoperable model that supports the documentation, analysis, and preservation of cultural heritage. The advantages of using BIM in the construction sector are now widely recognized. In recent years, research has been focused on achieving the same level of awareness and operability for the built architectural heritage (HBIM) and cultural heritage (CH) in general. Attempts to use BIM tools for CH have revealed limitations in the ability to accurately represent and convey information, particularly regarding cultural value and conservation activities. The lack of specific content in IFC hampers the interoperability of models, making it necessary to develop ontologies that conceptualize representative models of reality by defining classes, attributes, and relationships that describe a domain, and establish steps for the exchange of information between the geometric model and its semantic properties. This study proposes a method to improve the level of semantic enrichment and extend the knowledge representation domain currently offered by the most common BIM creation tools in an HBIM process related to fortified heritage. The parametric reconstruction of architectural objects, as seen in the diagram (figure), starts from the primary sources of treatises or textual descriptions to create reality-based 3D models. These models can be used and navigated within information systems that provide a complete, structured, and coherent semantic interpretation of CH through realistically reconstructed forms derived from historical sources and surveys. The construction Work Breakdown Structure is a useful tool in the context of fortress architecture since it helps to establish the different stages of the work through the organization of tasks related to conservation, restoration, or reconstruction of historic buildings according to a hierarchical framework. This model allows breaking down the project into manageable components and provides an orderly approach to the normally complex architectural intervention. Generally speaking, WBS starts from major elements, such as site preparation, structural analysis, and material assessment, down to detailed features of the restoration with regard to specific defensive features: walls, towers, bastions. Further, advanced digital technologies-like laser scanning and BIM modeling-are also integrated in the

Definition of a hierarchical structure carrying out the breakdown (WBS)



execution works so that the job is done with great precision. This construction WBS enhances coordination for this project by showing an involved scope clearly. It aids in the management of budget and time while making it possible to ensure each phase remains within the historical and architectural integrity of the fortifications, especially where those structures constitute parts of different historical periods and various construction techniques. This standard criteria underlined a hierarchical structure creation that would progressively decompose a project into smaller and manageable components. The top level represents the WBS or whole project, and then the next lower levels break down the project into what has been called tasks or work packages. This will ensure that WBS maintains a deliverables focus, stating what is to be done rather than how the work is to be executed. Each WBS activity has to be atomic, not in conflict; mutual exclusivity is the rule so that each does not duplicate or confuse the other.

This will also ensure that all components in the WBS must be measurable in terms of time, cost, and resources for more effectiveness in tracking and managing the whole project. The scope of every task or work package has to be well-defined with well-identified starting and ending points so that it is clear what is expected for its completion. This also relates to the 100% rule, which means all the work that has to be done to complete the project is recorded in the WBS-nothing that needs to be done is omitted.

It means that the WBS can also be elaborated progressively as the project evolves. It should begin with high-level tasks that get refined to more details over time. It is also very important at this stage that a well-designed WBS be flexible enough that changes can be made without affecting the integrity of the overall project organization. Finally, each work package must have clear responsibility assigned such that specific individuals or teams are accountable for completing each task.

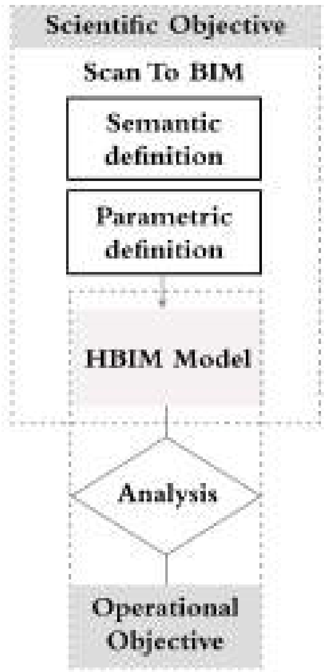


Fig. 7 Detail procedure: connection between scientific and operational objectives (Author's elaboration)

5. Digital architectural database for parametric definition and ontology integration in HBIM

The knowledge process developed during the survey and detection phase, based on the integration of the latest digital technologies, needs to be implemented within a BIM environment. Indeed, all the acquired data and information are challenging to manage with a traditional approach, which is characterized by a high risk of losing important and necessary data during intervention phases (Pelliccio et al., 2017). The construction of a 3D digital informative model also serves as a valuable support in the structural analysis phase and potential applications such as 3D printing of elements to be integrated. BIM 3D modeling plays a fundamental role in defining the geometry of gaps and supporting the modeling and creation of 3D printed elements.

Below are the main steps required in the HBIM process:

1. 1.Acquisition of historical-constructive information about the artifact: this action represents the first step in the correct application of the process, with a view to recovery and restoration consistent with the building's history.
2. Survey phase (Scan to BIM technology): indispensable for both the knowledge process of the asset and the subsequent graphic restitution phase.
3. Creation of models: from the three-dimensional surface (constituted by the tessellation of millions of points forming the cloud), the parametric BIM model is constructed. Considering the nature of the existing built environment, which almost never presents characteristics of regularity and repetitiveness, modeling is quite a complex operation.
4. Populating the model with documentary information:the HBIM model is considered complete only when the correlations within the data mass are active, allowing for querying from a historical documentary perspective, digital graphic processing, and the export of schedules necessary for cost or material quantification of the related interventions. Moreover, it is of fundamental importance to be able to integrate information into the model over time, throughout the life cycle of the asset, and to record any intervention or integration that occurs over the years.
5. Use of CDE (Common Data Environment): the integration of model-related information can be achieved

through the use of CDEs, which allow documentation to be stored in a shared cloud organized into specific directories, with managed access.

By following these steps, the HBIM process can effectively manage and preserve the historical and structural integrity of built heritage, ensuring that all interventions are well-documented and sustainable.

5.1 Parametric modelling HBIM

BIM can be defined as a holistic process that allows for the creation and management of multiple types of information regarding architectural heritage. In fact, all collected data can be gathered, combined, and digitally linked. (BS EN ISO 19650-2). BIM enables collaboration, software interoperability, process integration, and sustainability. In the case of Building Information Modeling, interoperability is represented by the ability to exchange the data contained in the model between different software and applications, through the IFC (Industry Foundation Classes) format, an open international standard developed by BuildingSMART International. BIM can be applied at various levels of maturity. As of 2017, the highest level of maturity observed is the so-called collaborative BIM. In architecture and engineering, the levels of detail, known as LOD (Level Of Detail), define the level of depth of information contained within the model. The characteristics of each LOD are defined by two important normative references, American and Italian[1]. HBIM extends BIM's capabilities to the creation of models of existing buildings. These are not just 3D digital and geometric restitutions but intelligent and information-rich models, whose elements are parametrically and semantically defined. The informative model built for each case of study reaches the LOD 200-300. High-resolution point clouds constitute the basis for modeling reality-based models. From the processing of models starting from survey data, libraries with parametric objects representing all the components of the artifact can be created. The fundamental difference between traditional BIM processes and HBIM processes lies in the nature of the information collected and the genesis and purpose of the model itself. The HBIM model originates from the documentary necessity of the current state. The survey and digital restitution of the building's geometric, construction, and conservation instances become central to defining the intervention.

Notes

1. The American Institute of Architects (AIA) publishes a Level Of Detail framework for the AIA G202-2013 Building Information Modeling Protocol. The Italian standard UNI 11337-4:2017 distinguishes between LOD, LOG, and LOI. In this context, the LOD, level of development of digital objects, is composed of LOG, level of geometric attributes development, and LOI, level of informative attributes development.

The concept of LOD, Level of Development, was introduced by the AIA in 2008, meaning the level of development. "The Level of Development describes the level of completeness to which a Model Element has been developed." A subsequent definition in 2013 states: "The Level of Development (LOD) describes the minimum dimensional, spatial, quantitative, qualitative, and other data inserted in a Model Element to support the authorized uses associated with that LOD." The literature presents extensive documentation on this topic, addressed by various regulatory bodies: BS – PAS 1192 – 2: 2013; BIM FORUM of AIA and BIM Toolkit: 2015; UNI 11337 – 4: 2017; EN ISO 19650 and UNI EN 17412-1. The British standard BS – PAS 1192: 2013 defines LOD as

The objective of the HBIM process, therefore, is to generate an informative model that is congruent and geometrically consistent with reality, containing most of the information collected up to that point (Pelliccio et al., 2017).
HBIM is an intelligent parametric model characterized by a detailed and well-defined information structure that can be continuously implemented, modified, and updated. Historical investigation and survey activities lead to the understanding of architectural, structural, geometric, and material characteristics of the building system to be preserved and conserved during the recovery design. The information and data included cover historical information, analysis of degradation or deformations, materials used, and the reliability level of the existing data. This results in the creation of a complete model. The application of the methodology to existing heritage, provides the opportunity to optimize management, maintenance, and protection, allowing for the monitoring of degradation, planning of restoration interventions, and simulation of catastrophic events.
A problematic aspect that a BIM model related to a historical building carries is the reliability of the measurements and the reported information. Therefore, the research and survey activity, which provides an accurate and safe reconstruction of the artifact, is crucial; for this reason, the theme of the model's reliability and transparency is fundamental to provide a precise awareness of the architectural object. Indicating the reliability and the interpretative level of the information in the model thus becomes a parameter of great importance and interest in the HBIM field.[2] The theme of transparency and reliability of the digital model visualization is of considerable importance, both in terms of geometric dimensional aspect and informational and knowledge aspect of the artifact.
Currently, at the regulatory level, referring to the UNI 113337 standard, the level of detail, the so-called LOD (Level of Detail), is defined, which allows for the classification of the elements present within the model based on geometric and informational accuracy and detail. However, there is no standard that defines and lays the foundations for determining and classifying the level of reliability of the information included in a digital model representing the built reality. This parameter is called LOR, Level of Reliability,[3] which testifies to the reliability of the data present within the digital model. Data acquisition, modeling, and information included in the models should be considered a continuously improving process. Considering that most of the built heritage lacks digital twins, the implementation of this methodology could

Level of model Definition for building and infrastructure projects: LOD (level of model detail) describes the graphic content,- LOI (level of information of the model) describes the non-graphic content.Integrated with the BIM Toolkit of 2015, it defines a numerical scale from 1 to 7 to correspond to the level of detail of the elements present in a model.The BIM FORUM of AIA defines Level of Detail referring to the amount of detail included in the model element. The Level of Development is the degree of definition of the element's geometry and the depth of attached information, the extent to which project team members can rely on the information using the model. Essentially, the Level of Detail can be thought of as an input to the element, while the Level of Development is a reliable output.

2. These themes related to data reliability were introduced by referring to the concept of model transparency of the state of the art starting from 2009 with the London Charter and later integrated in 2012 in the Seville Principles, albeit mainly aimed at the world of archaeology. The foundations of these arguments were already laid in 2003 with UNESCO's Charter on the Preservation of Digital Heritage. The London Charter's goal is to establish methodological principles to

ensure better management of the built heritage in the future, including all constructed works and those under construction, which necessarily foresee a design based on the BIM methodology.

In this case, the defined classification is as follows:

LOD 100 - Conceptual

The overall mass of the building representing area, height, volume, location, and orientation, modeled in three dimensions or represented by other data. Typically related to the pre-design or mass management phase.

LOD 200 – Approximate

Families are modeled as generalized systems or assemblies with approximate quantities, dimensions, shape, location, and orientation. Additional information can also be attached to the model. Corresponds to the preliminary design phase.

LOD 300 – Precise

Families are modeled as detailed assemblies accurately representing quantities, dimensions, shape, location, and orientation. Additional information can also be attached to the model. Analysis can be conducted based on the performance of the selected systems and the specific representation of the model. The digital element is well-defined both geometrically and informationally, attributable to the definitive design phase.

LOD 350 - Assemblies for Coordination

Families are modeled as detailed assemblies accurately representing specific systems, objects, or assemblies in terms of quantities, dimensions, shape, orientation, and interfaces with other construction systems with the necessary details for coordination and layout. Non-graphic information can also be attached to the model.

LOD 400 – Fabrication

Families are modeled as detailed assemblies accurately representing dimensions, shape, location, quantities, and orientation with complete fabrication, assembly, and detailing information. Additional information can also be attached to the model. Analysis can be conducted based on the performance of the selected systems and the specific elements present in the model. Corresponds to the executive or construction project phase, in which computational, performance, and realization aspects are defined.

ensure correct digital visualization, dissemination, and communication within the Cultural Heritage sector. The Seville Principles, on the other hand, represent a practical implementation that lays the foundations for these themes within the world of archaeology, attempting to make them actionable. Some principles dictated by the London Charter concern: implementation, which consists of inviting the adoption of the proposed guidelines through the development of a defined and determined methodology; research sources, related to the theme of transparency of the digital model and its information; documentation, which attempts to determine a definition of information organization through a process that starts from data processing to their visualization, thus attempting to guarantee a scientific, traceable, and unambiguous process. The goal is to define the process by which the image, model, or information is traced, disseminated, and made available, reaching a scientific and unambiguous definition related to the reliability and veracity of the data, whether geometric or informational in nature.

3. The reliability level of the information contained in a model representing the reality of an existing artifact remains a parameter lacking objectivity.

LOD 500 - Record Documents (Record BIM)

Families are modeled as actual constructed assemblies accurately representing dimensions, shape, location, quantities, and orientation. The model must be configured as a central data repository for integration into building maintenance. Additional information can also be attached to the modeled elements. Refers to the actual construction phase in which model elements are defined informatively concerning supply, installation, management, and maintenance aspects.

In line with the Italian standard UNI 11337 – 2: 2017, the level of development of the digital objects composing the models (LOD) defines the quantity and quality of their informational content and serves to achieve the objectives of the process phases, uses, and objectives of the model they refer to. Specifically, the Level of Detail (LOD) is intrinsically defined by the Level of Geometry (LOG) and Level of Information (LOI). The LOG indicates the geometric development that the elements in the model assume, while the LOI indicates the level of information that the elements in the model contain.

Coding Adopted in the HBIM Model

Using HBIM as novel prototype library of parametric objects, based on historic architectural data, in addition to a mapping system for plotting the library objects onto digital survey data. In this case the advantage of HBIM over other modelling approaches is that the end result generates automated conservation documentation. HBIM can be used as 3D digital semantic models organized as cognitive systems with geo-object items in a 3D Information System.

Models are an excellent means of understanding architecture, describable as a collection of structural objects, and identified through a precise architectural vocabulary. In this perspective, modeling does not follows exclusively a logic belonging to geometric criteria, rather this is a prerequisite upstream of a methodology based on architectural element as the basic unit and its construction methods as organizational tool.

To achieve an organized and structured model, it is expected that the families present in the model follow a coding system that identifies them and makes them unequivocally identifiable and unique. The parameters that distinguish the families are the family name and type.

There is currently no standard parameter that allows the determination of the quality and veracity of the data inserted into a BIM model. The issue of information transparency, introduced in the London Charter and reaffirmed in the Seville Principles, has led to the development of numerous studies aimed at establishing methodological principles to objectify information reliability in architectural heritage modeling. On this matter see: (Stefani C. Et al, 2010,) addressing the issue of temporal uncertainty regarding historical transformations; (De Luca L. Et al 2011), introduced the idea of modeling geometric elements with different color tones based on spatial and temporal uncertainty; (Apollonio F.I. et al, 2013), proposing a coding system based on color according to the uncertainty degree of the information sources categorized. Bianchini C. Et al, 2018, introduced LOR as a parameter in the BIM environment, related to digital elements to improve scientific rigor and interpretative transparency regarding architectural heritage; Maiezza P., in 2019, proposed a dual level of reliability for digital elements: LOA (Level of Accuracy): Refers to geometric accuracy measured as deviation. LOQ (Level of Quality): Refers to the informational content associated with the single element.

Regarding families, there are system families, whose name is already defined and not modifiable, and loadable families, whose name can be determined and modified. The type of family, however, can be modified regardless of whether the family is a system or loadable. In this case, the type of family is described considering the family, its technological function, and its geometry.
For the various BIM models developed according to the reference discipline, a coding system has been developed that identifies the adopted families, as described below.

1. Family Name: The identifier for the family itself.
2. Family Type: The category that can be modified to reflect specific characteristics, including:
- System Families: Names are predefined and cannot be changed.
- Loadable Families: Names can be assigned and modified as needed.
3. Technological Function: Describes the functional role of the family within the model.
4. Geometric Description: Details the geometry associated with the family, ensuring clarity and precision in the model.

The coding system developed for the BIM models according to the respective disciplines includes the following structure:

— Family Name: Clearly denotes the category and specific function.
— Family Type: Specifies whether the family is system-based or loadable.
— Function: Indicates the technological function, providing context for its role within the model.
— Geometry: Ensures that the geometric attributes are well-defined, enhancing the model's accuracy and usability.

This coding system ensures that each family within the HBIM model is uniquely identified, facilitating better management, updates, and consistency across the model.

<u>Unique Identification of Each Instance in the HBIM Model</u>
To uniquely identify each instance, certain project parameters have been defined and grouped under the category "Identity Data," creating a unique identification code for each element in the model. The adopted parameters are listed below:

1. Project: Defines the project name.
2. Fortress: Defines the building in which the instance is located.
3. Discipline: (e.g., Architectural) Defines the discipline to which the instance belongs.
4. Family: Defines the family of the instance, considering the previously mentioned family coding.
5. Type: Defines the family type of the instance, taking into account the type, technological function, and geometric dimensions.
6. Progressive Number: Defines how many instances of that family and type are present in the model.
7. Identifier: Uniquely identifies the instance, consisting of the combination of the previously mentioned parameters.

By following these parameters, each instance in the HBIM model can be uniquely and systematically identified, ensuring clarity and consistency across the modelling phase.

Regarding digital visualization transparency, Brusaporci S. in 2017 emphasized the importance of understanding and describing the critical interpretation of architectural and construction sources on which the model is based, as well as the process of structuring the modeling activity.
By addressing these aspects, one can ensure that the models created are not only accurate representations but also reliable sources of information for the conservation and management of architectural heritage.
The greater complexity of physical reality impacts both the creation of the model and the reliability of its elements.Various research groups have addressed issues related to accuracy, understood as the geometric precision of the parametric model compared to the numerical model of the point cloud (Chiabrando F., Campi M., and others). However, fewer studies evaluate the model in terms of proper structuring of semantic content and scientific reliability and philological transparency (Fiorani D.).

6. Promotion – Communication by image

Communication by image is the most immediate and intuitive especially if based on the semiotic structure thus generating "meaningful images" that relate to the referent/signifier/signified.

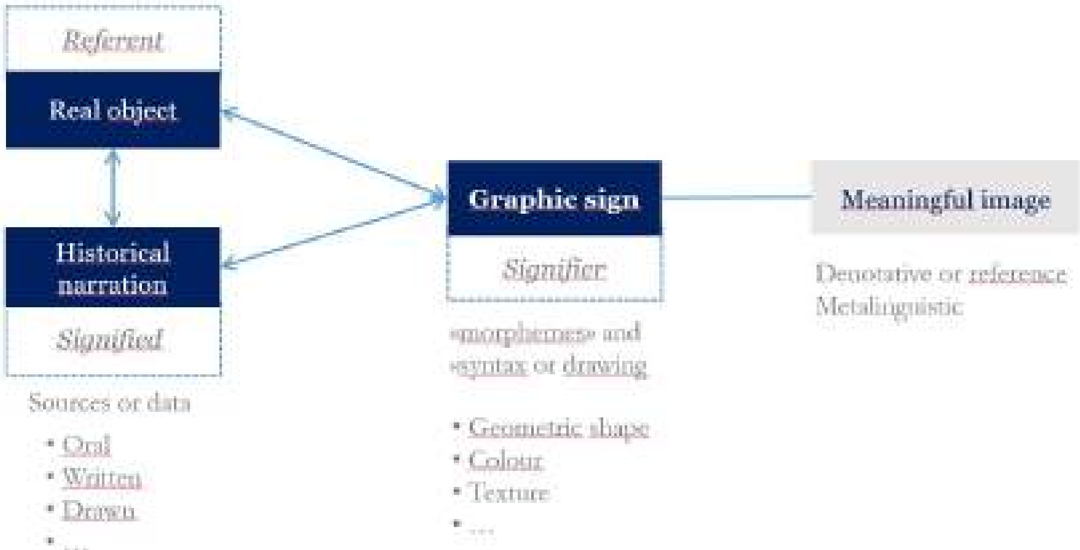


Fig. 8 Semiotic scheme of a meaningful image [Pelliccio, A., Saccucci, M. and Miele, V. (2022)]

6.1 The graphic sign for historical narration

Facing with remains of architecture, the observer elaborates on an image in his mind, reproducing a possible reconstruction of the real object as it was in the past. This image or reproduction, is neither realistic nor objective and could induce the observer to communicate a message that does not respond to reality. This is particularly wrong in the case of the historical narration of an architectural asset, which, on the other hand, requires a more denotative or referential communication. If performed with the use of images, the latter also becomes immediate and more easily transmitted to everyone, even the less experienced. The drawing works well because it represents the actual object as an icon or rather reproduces its formal, geometric, chromatic, and proportional qualities. Therefore, it is of great help in understanding the real phenomenon since it generates "meaningful images" with signs based on a precise grammatical structure and a uniquely determined visual code. In short, the drawing relates the signifier with the referent and/or the signifier with the signified based on precise rules (Fig. 1). [Joly, 2000 pp.44-79]. A real object can be represented by different models derived from further use of colour and geometry. A simplified geometric and monochromatic model (BIM) creates, for example, a mental image as it uses clues with logical affinity between the signs and what they represent (referent). The model conveys the "idea of the object" but does not make it realistically visible. For this reason, it is particularly effective, for example, in reproducing historical, hypothetical, or uncertain data as written sources since its features suggest the idea of a hypothesis rather than the certainty of the data. A further model, based on symbols, which are found in a conventional relationship between the signs and the referent, produces a virtual image, helping to understand even extensive and complex real phenomena. GIS, H-BIM, mesh, cloud point, and so on, are models that, born from the integration between heterogeneous survey data and historical sources, consciously project the observer into a virtual dimension. The virtual image, thus generated, has an exclusively epistemic function, even if the images produced are also metalinguistic since they explain, interpret, and comment on the signs with other signs, [Joly, 2008 pp.44-79]. The most intuitive model is undoubtedly the iconic one since it reproduces a visual image in which the real object appears exactly as it is. The icon creates an analogical relationship between the signs of the signifier and the referent. Generally, the texture is applied to the model to obtain photorealistic features that facilitate the reading and analysis of the material qualities and the spatial relationships between the object's components [Arnheim, 2020]. A model such as e.g. SMF, thanks to its photorealistic chromaticity, transmits information as data certainty, giving the observer a greater critical awareness in analyzing the real object. In summary, a cloud of points obtained with digital photogrammetry, for example, if discretized, returns a virtual image (symbol) of the real object, if reworked a mental image (clue) and if texturized a visual image (icon).

6.2 The three-level procedure for historical narration

Having said this, based on the denotative/metalinguistic function of visual representation, a procedure has been defined for the historical narration of architectural artifacts that have undergone multiple vicissitudes over the centuries. The phenomenon must be narrated starting from its dimensional consistency up to the events of the single architectural artifacts (towers, fortresses, and castles). The procedure relates the shapes and colours of the reproduction/image of the real object with the level of historical knowledge acquired from specific sources and by the survey. For this purpose, three

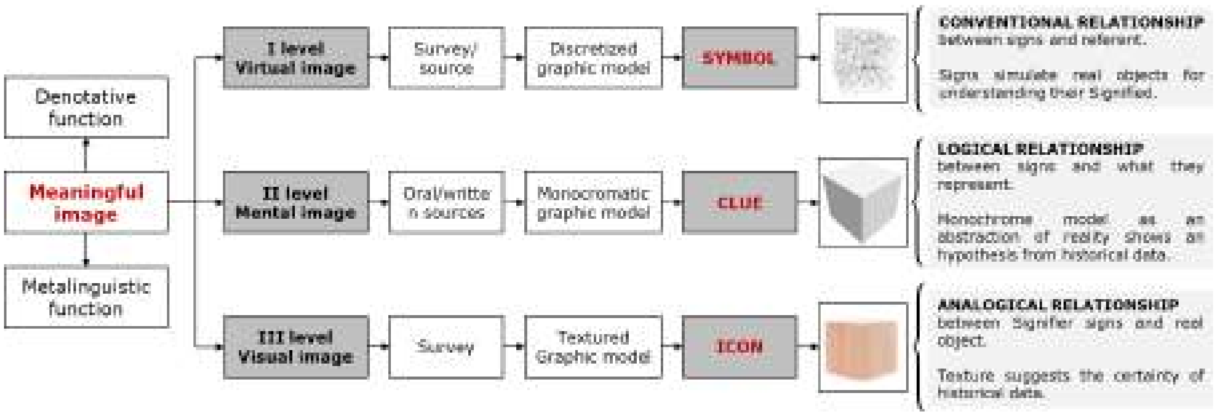


Fig. 9 Procedure scheme for the narration of the historical evolution of architecture. [Pelliccio, A., Saccucci, M. and Miele,V. (2022)]

linguistic levels of the graphic model have been defined (Fig. 9).

The first level is based on a virtual/symbolic graphic model (VSM), designed in a GIS environment to communicate, through images, information on a large scale of very heterogeneous data. The VSM model, with a denotative/ metalinguistic function, simplifies the message with graphic symbols but on certain data (integration of technical and historical maps). Its dynamic and virtual characteristics give the perception and awareness of the real phenomenon, which, given its dimension, can only be managed in a "potentially existing" environment and, therefore, virtual. On single artifacts, the VSM takes on a completely different function. Instead of simplifying communication, the symbols used in the model, eg. discretization, mesh, etc., are technical support and contribute to the creation of the next linguistic level, that is the mental/clue graphic model (MCM). The latter concerns, in fact, the single architectural artifacts and integrates historical data of different nature, primarily written ones. It is a model that, starting from the current state, through the Scan to Bim procedure, or the traditional survey, is imported into a CAD or H-BIM tool. Aware that no visual communication can be exclusively denotative, the model is reworked based on historical information or hypotheses,

Fig.10 Elaboration by the authors. In the VSM, the overlap between Tubert's Carte d'orientation with the current cartography. (Pelliccio 2022)

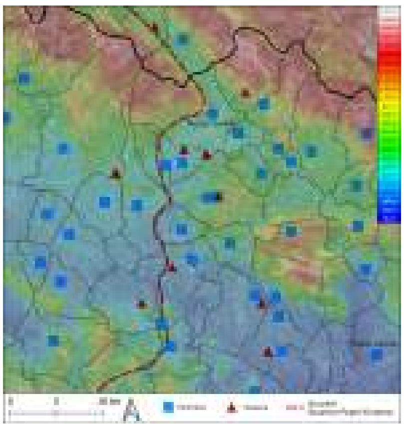


Fig. 11 GIS elaboration by the authors. FortLiriGis. The image symbolically shows the consistency of the fortification phenomenon in the border area. (Pelliccio 2022)

stripped of the texture (or photorealistic view), and simplified only to architectural volumes. In this way, the model is perceived as an abstraction from reality and transfers the idea that the historical evolution of its referent is hypothetical. Instead, starting from the assumption that the interpretation of colors, light, and shapes is anthropological, that is, that their perception is cultural and therefore natural [Mitchell, 2018 p. 59], the procedure applies this criterion to communicate the certainty of the information (data). The third linguistic level, which generates a visual/iconic model (VIM) by reproducing the architectural artifact as it is, is based precisely on the anthropological criterion. The visual rendering of the object is based on the acquisition of geometric, material, and dimensional data (certain and objective data), acquired with a Structure from Motion procedure then modeled in 3D, indeed. The model is then texturized or rendered, giving a photorealistic vision and, therefore, very similar to the object's reality.

6.3 The Virtual/Symbolic graphic model (VSM)

The different hypotheses on the structure of the fortresses phenomenon however point out a strong relationship between the morphology of the landscape, the topography of the place, the relationship with the polarizing elements, such as churches and castles, and the conformation of the architectural spaces. The Interpretation of such a significant phenomenon must necessarily make use of a virtual model capable of simultaneously restoring the territorial dimensionality and the interrelation of all factors. In the first phase of historical narration, whose only sources are the texts that describe the social aspects and not material realities, the communication must be denotative but at the same time virtual to visualize the complexity of the phenomenon. FortLiriGis, a symbolic virtual model born in a GIS environment, has this goal. The borders of the various duchies of the Liri Valley and all the towers, fortresses/castles have been geolocated inside the borders of the various dioceses, as reported in Toubert's "Carte d'orientation" [Toubert, 1973], georeferenced for the overlay with the current cartographic maps. (fig.10) A graphic symbol has been assigned to each element to make it more readable. The system produces heat maps that provide information on the distances to the main polarizing elements (e.g., churches and abbeys). The model also returns the altimetry, which is essential for understanding the architectural conformation of the individual sites and urban aggregates (territorium castri)

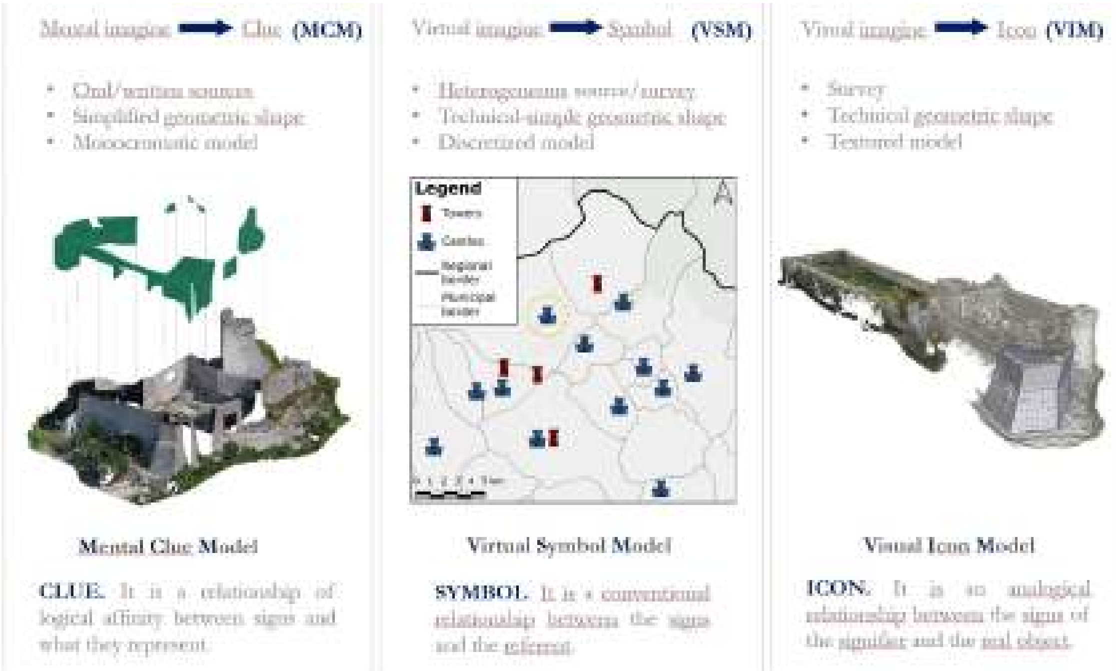


Fig.12. Schematic definition of the three models of represenation. (Elaboration by the author)

that are sometimes generated around the fortified core, thus suggesting a hypothesis on the reasons for the origins of these sites. FortLiriGis, which is designed on the metalinguistic indications suggested by the legislation, and created for the web, transfers to the less experienced observer an overview of this important phenomenon (Fig.11). This activates a significant process of enhancement of these sites, most of which currently is in a state of total abandonment.

The VSM model is also used in the analysis of individual architectural artifacts both in the GIS and HBIM environments. In FortLiriGIS, an alphanumeric and iconographic database is associated with the graphic symbol of each artifact, which collects historical data and displays them with a slideshow.

In the case of HBIM models, the geometric structure, acquired as cloud points, is used to bring communication to the next linguistic level or, in many cases, it helps technicians understand not only the signifier of the referent but also its meaning.

Fig. 13 Use the MCM model dictated by the uncertainty of the historical information and so the graphical processing is hypothetical. (Elaboration by the author)

6.4The Mental/Circumstantial graphic model (MCM)

The second linguistic level starts from the VSM and uses a mental/clue graphic model (MCM), which has been fundamental to putting together the historical information of the two fortresses, many of them drawn exclusively from written texts. The dates and reasons for their construction, as well as the original architectural structure, are as uncertain as to the phenomenon of fortification. From the analysis of the written sources, the hypothetical historical evolution of the two fortresses can be divided into three main phases, as shown in figure 6. The three-dimensional and monochromatic MCM model (Fig. 6) aims to transform the linguistic sign (written sources) into a visual sign by synthetically reproducing the narrated object and thus establishing a circumstantial relationship between the narrated reality and the image, according to an intuitive and immediate recognition code [Pelliccio, 2000]. If iconographic sources exist, the integration between MCM and historical drawings reduces the abstraction of the model itself, and the communication becomes intermediate between the second and third linguistic levels previously defined (Fig. 7).

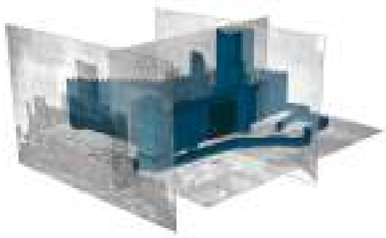


Fig. 14 Iconographics integrated with MCM model. Intermediate level of communication between hypothesis and data certainty. (Pelliccio 2022)

6.5 The Visual/Iconic graphic model (VIM)

The third linguistic level uses the visual/iconic graphic model (VIM), which, like the previous ones, is in any case structured on state of the art acquired with digital survey procedures. In this case, the model with which the texture is associated replicates the real object in its dimensions and its material characteristics.

The photorealistic chromaticity of the images transmits information as a certainty of the data and pushes the observer to a more careful critical analysis (Fig.8).

Furthermore, the VIM takes on particular importance also in the narration of the restoration interventions that have not rigorously applied the reversibility criterion introduced by Cesare Brandi. In this case, the model integrates the mental/clue level with the visual/iconic one. Various colorimetric choices, such as photorealistic textures for the historically original elements, and compact grey applied to a simplified geometry for the architectural part introduced by the restoration, virtually apply the concept of distinguishability, thus communicating the correctness of the historical data.

Fig. 15 VIM model based on digital photogrammetric surveys with drones. The models are textured to communicate the certainty of the data. (Pelliccio 2022)

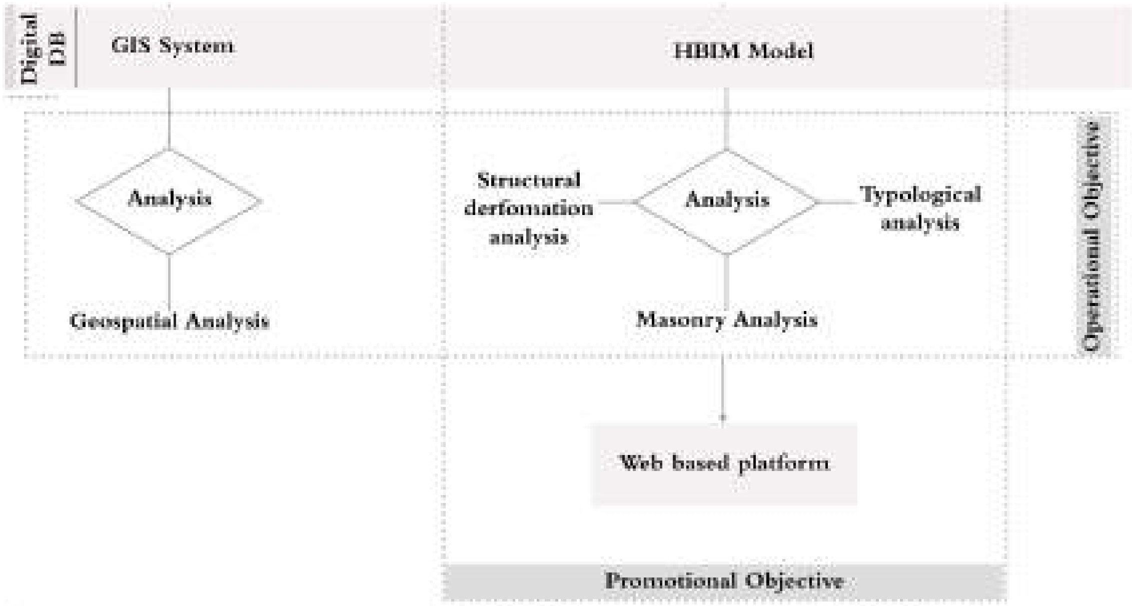


Fig. 16 Detail procedure: connection between operational and promotional objectives (Author's elaboration)

7. Analysis

All the data and databases constructed can help in the formulation of analyses and further investigations. the same process of acquiring survey data of the material consistency of fortified architecture, then SfM technology, led to the development of a deformation analysis of the elements of fortifications.

7.1. Deformations of the fortress towers analyzed by the SfM survey

SfM survey and SCAN to BIM can be used to understand the state of conservation of complex architectures located in inaccessible places. The analysis in the detail study of this research focuses on the geometric deformation of the Lazio fortresses, suggesting important information for the structural interventions.

Analyzing structural deformations or masonry cracks in this type of architecture is complicated and requires very long information acquisition and processing times when using traditional procedures. Digital photogrammetric surveys with drones greatly help and support analysis with high-quality standards. The digital survey, returning 3D models with high

precision, activates a fundamental process of conservation of historical places, already vulnerable, especially located at high seismic risk, such as the Italian Apennine region.
most of them are located on natural overhangs, used for defense purposes, and have colossal architectural components. The procedure aims to define an analysis capable of parameterizing the geometries of the most essential building components, such as the towers, obtaining theoretical three-dimensional geometric models to be compared with the actual models acquired with the SfM survey for reliable assessment of possible structural deformations [Saccucci et al., 2022].
A significant contribution in this area is the development of a reliable procedure, referred to as ThEM (Thematic Evaluation Model), which uses geometric parameterization to provide deformation values and assess the conservation state of these structures. The procedure was applied to the towers of fortresses in lower Lazio, specifically the fortresses of Sora, Vicalvi, Alvito, and Gaeta. The four case studies, despite their construction in different periods, underwent modifications between the 15th and 16th centuries and were chosen for their diverse layouts according to varying orographic conditions. The analysis involved selecting the most challenging-to-access tower within each fortress for detailed examination. Among towers with similar geometries, those with heterogeneous mass distribution were chosen. A semantic-functional analysis helped identify surviving components such as corbels and merlons, which are crucial for analyzing deformation.
The choice of the case studies is dictated by temporal coherence because these buildings all date back to the Early Middle Ages, at least in their original nucleus, with typological-structural characteristics, a mediocre state of conservation and the absence of previous restoration interventions, except for the Angevin castle of Gaeta which has undergone a partial restoration of only a branch of the internal rooms [Pelliccio et al., 2022].
The analysis focuses on the towers because their size and location complicate the acquisition of both geometric and material data, but also because they have very similar geometries.
Unfortunately, neither texts nor archival material have survived containing information on the archetypal shape of medieval towers in the geographical area analyzed. In any case, bibliographic research, such as the volume by Luigi Centra [Centra, 2020], which collects an interesting photographic apparatus of castles, towers and fortifications in lower Lazio,

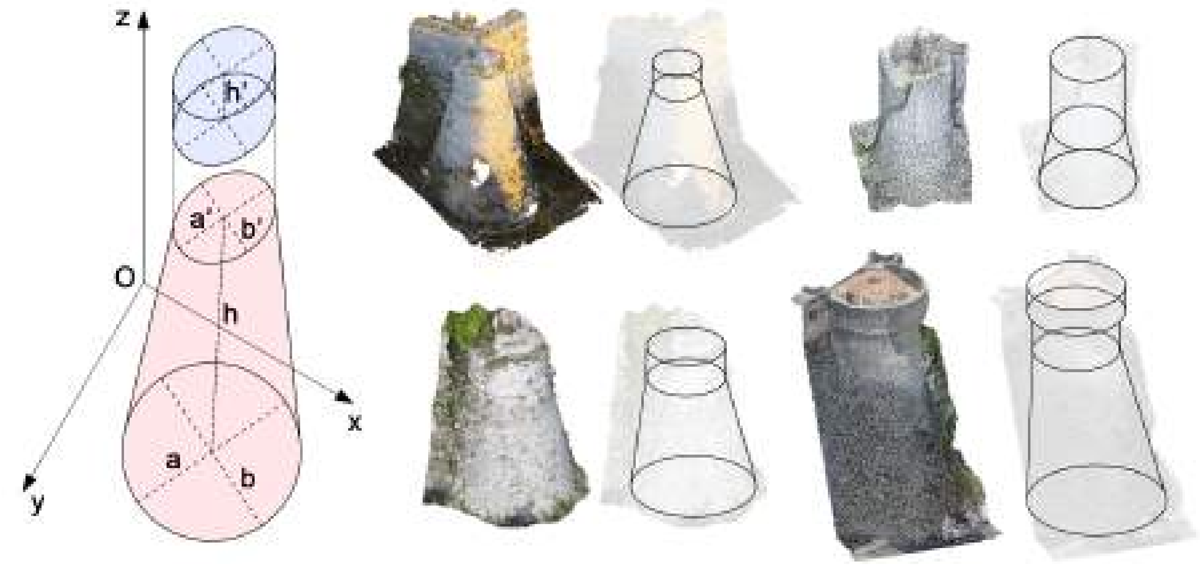


Fig.17 Theoric models: identification of the regular solids defining the geometry of the towers

and numerous other studiesidentify the most widespread geometries, such as the square, rectangular, circular, and truncated cone towers. Furthermore, the SfM survey of a conspicuous number of fortifications, in the geographical region of interest, was of great help in the benchmarking between the towers, most of which have a similar geometry.

The analyzed towers, in fact, varying in height between 12 and 25 meters, are composed of two superimposed solids, an elliptical truncated cone as a base, with an elliptical cylinder above it, which often has alternating corbels as decorative elements.

The workflow of the procedure is characterized by four phases as follows:

1. Extrapolation of elements of analysis, e.g. tower, from general photogrammetry obtained with a drone survey;

2. Acquisition, from the photogrammetric survey, of the parameters for the 3D construction of the regular solids, which make up the towers or theoretical model;

3. 3D model of the towers, obtained from the point cloud or empirical/real model;

4. comparison between the theoretical and real models for the evaluation of geometric-structural deformations.

From the rectified 3D point cloud, the main geometric parameters were extrapolated to define the 3D solids that make up the architecture of the towers. In particular the parameters (a,b,a',b',h,h') are acquired, and the elliptical truncated cone and the elliptical cylinder are modeled [Spallone, 2015]. The empirical/real model was then analyzed from the same point cloud, obtaining the sections both parallel to the base with a pitch of 2.00m and radial every 30°
For each tower of each case study, one superimposes the radial and parallel sections of the real/empirical and theoretical model, evaluating the deviations.

The amount of deformation, expressed as a percentage, is obtained from the following formula:

In which:
- A_r = area of the n-th section of the real model;
- A_t = area of the n-th section of the theoretical model.

Based on the calculated deformations (ε), the average percentage obtained is approximately 1%, which is notable concerning the size of the architectural element. Moreover, from the comparison between the analyses of the deformation of the tower type of the different case studies, it emerges that the deformation behavior is very similar. The reasons are to be found in the lousy execution during the construction phases of the work, from the structural settlement that the towers may have undergone immediately after their execution to achieve internal equilibrium, and from neglect and aging of the structure. The comparison also shows that the geometric region that presents a more significant deformation state is placed on average at 1/3 of the height of the truncated cone.

The procedure, however, suggests some important aspects. First, the percentage of deformation, which emerges from the comparison, highlights the state of conservation of the tower. A very high deviation, for example, indicates a probable structural instability which must be verified with appropriate structural assessment software. Obviously, the point cloud

obtained with the SfM survey is of great help as it can return, with adequate post-processing and more detailed knowledge of architecture elements, a discretized model in Shell or in macro elements for a FEM analysis.
Moreover, if the deviation is also associated with a deformation due to cracking, the analysis, in addition to the structural evaluation, suggests the urgency of structural interventions considering that the area in which they are located is highly seismic.
In summary, the proposed procedure provides for a fast survey, which, as mentioned above, would be difficult to implement due to the complex localization and size of the architectures. In this way it is possible to easily recognize any problems related to the state of conservation of the tower.
The numerous fortresses and castles of the imposing fortification process, which southern Lazio experienced between the high and low Middle Ages, have profoundly changed the landscape, becoming essential elements of identity for the local population. They generally occupy the top areas of the hills. The acquisition of data for a correct analysis of their state of conservation becomes very complex if we do not use the SfM survey technologies. procedure that, based on the acquisition of survey data from a drone, allows a reliable analysis of deformations, providing asset managers with adequate tools in decision-making for their recovery.

To summerise, precise measurements of the towers' geometric dimensions are obtained using photogrammetric survey techniques. This process allows for the creation of geometric primitives based on treatise specifications. Two types of elliptical solids—a cylinder and a truncated cone—were used for all four towers. The dimensions of these solids were determined by measuring the ellipses of their top and bottom bases, with the height calculated through trigonometric operations.
Constructing a three-dimensional model of a tower becomes straightforward once the geometric primitives are established. The tower's geometry is formed by combining these solids into a single theoretical volume. A mesh surface from the digital photogrammetry point cloud can also create the empirical model of the tower. With both models, transversal sections parallel to the horizontal bases and longitudinal sections passing through the tower's central axis can be easily extracted.
The structure of the tower can be meticulously studied by extracting cross-sections at 30 cm intervals, corresponding to

the size of the stones. The deviation in distance and surface deformation between the theoretical and empirical models are assessed by superimposing them. Displacement data for each section were analyzed and interpolated for the entire height of the tower. The results are visualized on a color graph, indicating the maximum deformation value area in red.

Initially, there was some skepticism about the reliability of this deformation analysis comparing theoretical and empirical models. To verify its accuracy, the results with those from a finite element (FEM) model were compared. The FEM model was constructed with 1983 nodes and 1920 shell elements, each about 30 cm x 30 cm, similar to a stone ashlar. Masonry thickness was parameterized using detailed site surveys and estimated for inaccessible areas, while internal cavities were modeled with shells confirmed in reality. After defining all load conditions, deformation analysis was conducted.

The findings revealed that FEM analysis results were not only similar but also comparable to those obtained from SfM experimentation. The deformation states were both qualitatively and quantitatively comparable, with the most deformed areas aligning and the deformation values being of the same order of magnitude. With survey precision at the millimeter level, the reliability of the results was affirmed, consistent with the precision of the deformation values obtained.

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8. Final results - informational and operational sheets

The results of procedure applied on five selected cases of study is then summerised in sheets constructed according to ICCD cataloguing standards and expanded and adapted to the procedure. The following case study sheets provide a comprehensive overview of various fortified architectural sites, emphasizing both their historical significance and their current state of preservation. Each sheet is structured to offer detailed information about the site's geographical location, historical development, and architectural characteristics, as well as an analysis of its conservation needs and the methodologies used for documentation and restoration planning. The information is organized to facilitate a clear understanding of the site's material conditions and historical layers, following modern conservation principles. Advanced digital tools, such as GIS, photogrammetry, and HBIM, are employed to enhance the study of these fortifications, offering innovative approaches to documenting, analyzing, and preserving architectural heritage. These methods allow for accurate and non-invasive surveys, providing valuable data for future restoration projects while ensuring minimal impact on the physical integrity of the structures.

The case studies also incorporate theoretical models and empirical analysis to assess the structural deformations and material conditions of the sites, ensuring a detailed understanding of the conservation challenges each site faces. Through these sheets, a holistic approach to the management and preservation of fortified heritage is outlined, integrating historical research with cutting-edge technology to support long-term conservation strategies.

"General Information" Board
This section provides essential preliminary data to contextualize the site from geographical, historical, and material perspectives. It includes information such as altitude, geographical coordinates, and ownership (public or private), forming the basis for understanding the fortification's setting. The description of the site's conservation status, integrity, and authenticity is crucial for guiding future restoration decisions, adhering to the principles of the Venice Charter (1964), which stresses the importance of preserving both material integrity and cultural authenticity. The details of the construction materials, such as the opus incertum in local calcarenite stone, are part of a typological analysis of the masonry, informing conservation efforts that respect the original construction techniques and the historical evolution of the structure.

"Historical Board" Board
The chronology in this section outlines the site's historical development, highlighting changes in ownership, architectural transformations, and functional shifts. Given the difficulty of obtaining precise historical data, an evolutionary hypothesis of the structure is provided, based on the analysis of available sources and archaeological evidence. This stratigraphic synthesis identifies the most significant periods and any overlapping architectural interventions. Modern conservation theories emphasize the need to respect historical layers, preserving traces of the past without erasing them. This approach enables a deeper understanding of the building's evolutionary phases and helps preserve its historical and cultural complexity.

"GIS to BIM" Board
This section describes the integration of GIS data into BIM models to analyze the relationship between fortifications and their surrounding territories. The territorial analysis assesses the intervisibility between different structures, a critical factor in the construction of medieval defense networks. This

approach follows modern Conservation Management Planning (CMP) guidelines, which advocate for the use of digital tools in managing and enhancing architectural heritage. BIM (Building Information Modeling) not only digitally represents the site but also integrates stratified data useful for long-term management, providing a dynamic tool for planning restorations, maintenance interventions, and scientific studies of the territorial context.

"Digital Survey" Board

The digital survey is conducted using aerial photogrammetry techniques and drones. The images captured are used to create highly accurate 3D models of the site with minimal margin of error. Drone photogrammetry is particularly effective for accessing difficult or remote locations, enabling the collection of precise data even in challenging environments. This non-invasive survey method, in line with the recommendations of the London Charter (2007), allows for detailed documentation of the structure without compromising its physical integrity. Digital surveys are especially beneficial for vulnerable historical structures, providing the detailed information necessary for future restoration while monitoring any changes or deterioration over time.

HBIM Modeling Board

This section details the process of HBIM (Heritage Building Information Modeling), describing the digitization of the site through the "Scan to BIM" technique, which begins with a point cloud generated from the survey data to create detailed 3D models. HBIM goes beyond mere geometric representation, incorporating parametric information on materials, construction techniques, and historical attributes of the building. The use of HBIM marks an evolution in heritage management and conservation, enabling simulations of restoration scenarios and the assessment of intervention impacts before they are implemented. Additionally, the digital model can integrate conservation status data, supporting informed decisions based on a precise analysis of the structure's current condition.

Deformation Analysis Board

The structural deformation analysis is based on a comparison between theoretical models—derived from the ideal proportions of the structure—and empirical models obtained through photogrammetric surveys. This approach, inspired by scientific restoration theory, allows for the identification of shifts or deformations in the structure over time, providing critical data for consolidation interventions. The areas of greatest deformation are visually highlighted, helping to accurately pinpoint where interventions are needed, while adhering to the principles of minimal intervention and reversibility recommended by contemporary conservation theories.

Masonry Analysis Board

This section offers a detailed examination of the masonry's composition and construction techniques. The analysis of materials, such as local calcarenite stone and aerial lime mortar, follows the principle of preserving original materials, ensuring that interventions retain as much of the original materials and construction methods as possible. Characteristics such as the shape, size of the blocks, joint types, and stratifications are analyzed to determine the construction technique and any modifications made over time. Modern conservation theories advocate for the use of compatible materials and restoration techniques that respect the original features of the structure, ensuring long-term stability without compromising its historical readability.

V

DETAILED STUDY

SORA

VICALVI

ALVITO

CASSINO

GAETA

Detailed study. Cases of study

1. Historical framework

The study of the defenisve structures development is a labyrinthine and complex work, taking into account the mere fact that each specific castle just about represents the individual flow of its development, partial destruction, and further re-building. From the 10th to the early 12th century fortifications predominantly relied on the fences, earthworks, and walls, – though the structural solidity depended on different factors. With the introduction of modern technologies and more consolidated menace, the strategic fundamental turns toward defense took place. During this period, it passed from being basically wooden to much solid materials such as bricks and stones. With the introduction of such better materials, there was the necessity to rethink designs in fortification regarding better placing of salient elements such as towers, gates, and curtains. It is for this reason that a comprehensive study of the fortifications in southern Lazio must deal with an extremely precise historic-geographic and territorial analysis in the interests of full understanding of the complex nature of the phenomenon in an overall rich yet fragmented context.

Fig.1 Latium adiectum map in the 7 BC, (https://www.antichita.uniroma1.it/- last access 25.09.24)

1. Southern Lazio in the Middle Ages: a complex historical region

Southern Lazio in the Middle Ages presents itself as a composite region with a complex history. The significant Roman heritage, with its network of civitates, consular roads, reclamations, rustic and imperial villas, seems to be the first reference point giving an indelible shape to the territory. However, in the central centuries of the period under consideration, around the year 1000, this region grew on different parameters[1], superimposed on the long period of Roman modeling [Giammaria G., 1998]. It is not possible to clearly indicate, using geographical, historical, or cultural criteria, the region defined as southern Lazio except by indicating the territory south of Rome. Using classical categories, it could correspond to the part of the Latium adiectum. Today's Lazio is a composite region, generated by detachments and unions of territories previously belonging to different states, formed as a result of a centuries-long process culminating in significant events at the time of the Unification of Italy and towards the end of the 1920s.

In the Middle Ages, the current Southern Lazio was divided between the Church's dominion[5] and various southern institutional entities: the region underwent significant transformations that overturned its realities and presented pronounced polymorphism. The political division of present-day Lazio occurred with the Lombard advance from the south, which settled in successive waves along the Liri River, the border from the 8th century onwards, between the lands gravitating around Rome and those belonging to the southern government entities. Below the Liri, various political organisms were established, never truly dependent on central authorities, remaining formally autonomous until the establishment of the Norman-Swabian State. In this territory, several lordships were present; the secular ones were all of Lombard origin, while among the ecclesiastical ones, the Cassinese abbey emerged, managing to form a vast property and dominion, often subjected to the offensives of neighboring lords. The Norman-Swabian State gave political unity and subjected the feudal lords, subjecting the territory to formally unitary directions[2]. Beyond the Liri, in the Ducatus Romanus, after the collapse of Byzantine power, the papacy prevailed, but a process of subjugation was completed under Innocent III.

In both areas, the scant sources preceding the 10th century indicate a population decline. Despite the demographic collapse, the population was distributed over wide spaces; there were not only scattered settlements, but during the Byzantine period, a series of centers appeared, mostly coinciding with the ancient civitates. From the 8th century onwards, the Cassinese monastery returned as an institutional, economic, and religious reference point for the entire area, initiating a new order due to Carolingian policy, aimed at controlling the papacy and the Salernitan Lombards [Bloch, H., 1986]. In the centuries from the fall of the Roman Empire to the year 1000, Southern Lazio experienced a deep economic crisis. Despite the Carolingian reordering process, local dominants prevailed, aiming at territorial expansion without having the strength to subdue or absorb neighboring powers. Various centers of political and economic aggregation were determined, particularly coastal centers around Gaeta, and inland, between Montecassino, the lower Liri Valley, and the Val di Comino. These were vast lordships ranging from Gaeta[4], controlling the gulf, to the counties of Aquino-Pontecorvo, in the middle Liri Valley, to the revived Cassinese lordship, active in the territory straddling three regions: Abruzzo, Lazio, and Molise, up to the Marsi emerging in Val di Comino.

The years of the German emperors also marked the arrival of new marauders, the Normans, religious reforms, and political turbulence, making Southern Lazio a place of transit, negotiations, meetings, and clashes. The demographic increase underpinned the propulsive drive that led to a new design of settlements, through the concentration of population: the incastellamento that characterizes the demographic and cultural order of the entire Southern Lazio.
The model outlined by Toubert, cited earlier in this study, highlighted the central role of the feudal ruling class and ecclesiastical institutions. The visible product of the incastellamento is the castrum, usually built on a hill, surrounded by walls, containing rural dwellings and the lordly palace as well as the village churches. The model does not deviate from the morphological characteristics of the ancient civitates, but it proves innovative for the transformation from an external territory to a walled village. The widespread construction of castra is also connected to the building of fortresses and a network of fortifications.

Between the 12th and 13th centuries, this area regained the centrality it had previously held. The main protagonists, the popes and Sicilian kings, wove policies superior to the forces in the field and on very broad strategic scenarios; secondary actors were the feudal powers. Some baronial families of the Kingdom of Sicily had Lombard origins, others arrived with the Ottonians or the Normans and Swabians; in the papal state, they were mostly Latin and Roman families. In the Neapolitan kingdom, feudal changes followed dynastic trends: the previous framework was regularly overturned with the arrival of new conquerors: first the aforementioned Lombards, then the Normans, finally the Swabians, Angevins, and Aragonese brought their men, leading to a secular turnover that periodically changed the Neapolitan baronage.

The barons were a continuously fluctuating class involved in political-military clashes; they practiced permanent warfare, resulting in the need to build strongholds to defend pressing interests. There was no reason or necessity for a barrier between state and state; for this function, it was necessary to develop a semaphore and information system.

We do not know when the semaphore system was implemented; in the papal domains, it should date back to the pontificate of Gregory IX, if his reorganization of defenses through the castellated network subject to the Church is interpreted in this way. In the 14th century, a significant change occurred compared to previous balances. The case was no different in the Kingdom of Naples, where despite the presence of a powerful centralized monarchy, the barons strengthened their role and powers, effectively conditioning the Angevin rulers. These events and the 14th-century struggles, the role that Southern Lazio had in the Western Schism, the near annexation of the Kingdom of Naples by Durazzo, the renewed and failed attempts by the Caetani to establish a lordship, and the successful foundation of the vast interstate state of the Colonna, further fragmented the scene of Lazio south of Rome, making it a region of varied characteristics.[3]

A crisis that is felt from the abandonment of villages in the second half of the 14th century and the early 15th century developed as the decline and disappearance of the ancient lordships in both areas that make up this part of Lazio. The resumption of international conflicts in the 16th century, between France and Spain, directly involved the area; affected by modern warfare, causing the transformation of many fortresses with adjustments to contemporary fortification techniques, Southern Lazio underwent another transfer of powers after the change of the state apex; in the Kingdom of Naples, there was the usual lordly turnover with the introduction of other houses loyal to the Spanish crown. Beyond the Liri, a strengthening of papal authority was underway, with a slow process of power concentration. After the Italian Wars, the Spanish peace was disturbed by the War of the Campagna, the last episode of the 16th-century duel between France and Spain, which can be considered the event that ended the process of transforming the fortresses. In the Neapolitan area, many of them were reduced to residences, others began the dismantling process; in the papal area, the most significant changes occurred: with the Treaty of Cave, the southern frontier was demilitarized, fortresses and strongholds were demolished, only in isolated cases were the buildings reused as villas or palaces, but mostly they began to be abandoned.

The historical framework outlined allows for a better understanding of the fortified structures present in Southern Lazio. Several questions arise in front of the vast yet hidden and little-known fortified heritage. In addition to fundamental questions about consistency and territorial arrangement, as well as historical-institutional framing, many revolve around possible relationships between fortresses and territory and construction techniques, in the absence of rich contemporary documentary sources and still improbable archaeological excavations. All these questions refer to the genetics of the fortified site, understood both as historical investigation and architectural study and fortification techniques.Based on all these knowledge is then stated an hypothesis for the evolution of the fortresses identified.

Notes

1. The interaction between the ancient Roman settlements and the new sites born of encastellation was already intuited in the late twentieth century: "it seems that the model of the castrum is to be found in the civitas; such a discourse, with all possible cautions and with all the intervening variations, seems to have a its own consistency, since the main distributional pattern of the castrum is one that derives from the Roman city layout and as transposed by the urban planning tradition of southern Latium." G. Giammaria, De roccis, turribus atque fortellitiis. Le rocche del Lazio meridionale nel Medioevo, in Castelli del Lazio meridionale, a cura di G. Giammaria, Roma-Bari 1998.

2. See Toubert, Pour une histoire cit.; for developments in the period of the Norman advance, see Id. La terre et les hommes cit.

3. Coccia, S. (1998). Castelli del Lazio meridionale: contributi di storia, architettura ed archeologia. Laterza.

4. On the encastellation of the Gaeta territory, the contributions of Giraud, Le réseau cit. and Delogu, Il Ducato di Gaeta cit. are fundamental.

5. For an overview of the vast bibliography on the processes of christianisation and Christian organisation of the countryside of Lazio see V. Fiocchi Nicolai 1999. Alle origini della parrocchia rurale nel Lazio (IVVI sec.), in: Alle origini della parrocchia rurale (IV-VIII sec.). Atti della giornata tematica dei Seminari di Archeologia Cristiana (École Française de Rome, 19 marzo 1998), Città del Vaticano, 445-485 and Cantino Wataghin, G., V. Fiocchi Nicolai and G. Volpe 2007. Aspetti della cristianizzazione degli agglomerati secondari, in: di R.M.Bonacasa Carra and E. Vitale (ed), La cristianizzazione in Italia fra tardoantico e altomedioevo. Atti del IX Congresso Nazionale di Archeologia Cristiana (Agrigento, 20-25 novembre 2004), Palermo, 2007, 85-130. On the relationship between rural churches and local communities between late Antiquity and the high middle ages see A. Chavarria Arnau 2008, Chiese, territorio e dinamiche del popolamento nelle campagne tra tardoantico e alto medioevo, Hortus Artium Medievalium 14, 7-28.

6. Archeological studies on the region Latium Adiectum, See Crova C., 2005, Insediamenti e tecniche costruttive medievali. Il Latium adiectum e la Terra Laboris, Montecassino.; De Rossi G.M., 1980, Il Lazio Meridionale, Roma.; Hayes J. W., Martini I. P., 1994 (ed.), Archaeological Survey in the Lower Liri Valley, Central Italy, B.A.R. International series 595, Oxford.

7. Archival data: Archivio di Stato di Bari, Archivio Caracciolo Carafa di Santeramo; Archivio Fondazione Camillo Caetani; Annales Ceccanenses (a c. di G. Pertz, Hannover 1866) [Monumenta Germaniae Historica, Scriptores XIX, pp. 275-302]. Ravennatis Anonymi Cosmographia et Guidonis Geographica, in Itineraria Romana, II, a c. di J. Schnetz, Lipsia 1940.;Chronica Monasterii Casinensis (a. c. di H. Hoffmann, Hannover 1984 [Monumenta Germaniae Historica, Scriptores, XXXIV]).; Chronicon Volturnense (a c. di V. Federici, Roma 1925 [Fonti per la storia d'Italia, Istituto storico per il Medioevo, LVII]).;Erchemperti Hystoriola Langobardorum Beneventanorum (a. c. di L. A. Berto, Napoli 2014). Pauli Diaconi Historia Langobardorum (a. c. di L. Capo, Milano 1992 [Fondazione Lorenzo Valla – Scrittori greci e latini]); Codex Diplomaticus Cajetanus, Tabularium Casinense, editus cura et studio Monachorum S. Benedicti Archicoenobii Montis Casini, t. I, pars. I, e t. II, pars. II, Montis Casini 1887, t. I, doc. 130 (1014), pp. 244 -252, e t. II, doc. 246 (1072-73), pp. 114-115.

2. State of knowledge on the fortresses of Southern Lazio:

- History of architecture and building techniques:
Research on historical-territorial frameworks, some investigations on individual castles, and the major work on incastellamento by Pierre Toubert (Les structures, 1973). His study has clarified how the aggregation of inhabitants from previous scattered residentiality to new demographic centers, the political will expressed by territorial lords, the new land and cultural order, and the possibilities allowed by the increase in available workforce are the prerequisites that, in a short time, enable the construction of an articulated set of fortified settlements, including a high number of fortresses.

- Giacomo Bascapè and Carlo Perogalli (1968) apply a classification defined by previous castellological studies: they describe a group of fortresses through cards, distinguishing between mountain castles, more adherent to the orography and environmental characteristics of the place, and others of the plain with a more regular layout. They apply the traditional genetic vision of castles to Lazio: enclosure, tower, enclosure with tower, enclosure with residential building, and believe that there are two circuits of papal rocks, one in Campagna, the other Marittima. They identify a third defensive system along the coast, identifying different structures: some castles recall constructions in Northern Italy (attributed to the emigration of Lombard workers as a source of technical contamination), while others, like Vicalvi, find no comparisons outside Lazio. They note the rarity of circular towers and observe how the Rocca tends to emerge from the settlement but is often located in the distance.

Bascapè, G., Perogalli, C., (1968) Castelli del Lazio, Bramante Editrice, Milano

- The archeologist and historian Giuseppe Marchetti Longhi focused on the fortresses of the papal territories, framing the fortresses in relation to existing castellane lordships. Besides classifying the fortresses by position, he uses other functional criteria: castles destined for territorial control, border defense, or with semaphore function.

Marchetti Longhi, G., (1967-68), Una passeggiata storica attraverso i castelli del Lazio Meridionale, in Bollettino dell'Istituto di storia e arte del Lazio meridionale, V, pp.99-176)

- Lucio Santoro (1982) identifies in the Terra di Lavoro area, which merged into the province of Frosinone, the two castellane systems of Montecassino, erected to defend the Benedictine cenobium's patrimonial goods, and the d'Aquino, a feudal dynasty branching in the middle Liri Valley. He considers the tower and the keep the main elements of the fortresses as they constitute the defense's strong point and believes that only by distancing the fortresses from the villages

Santoro, L. (1982). Castelli angioini e aragonesi nel Regno di Napoli. Rusconi immagini.

did the castles manage to develop their characteristics fully. Santoro found that the d'Aquino built many fortresses, most of which are now transformed or disappeared, and recalls Alvito and Vicalvi in this regard; the former remained a fortress, the latter became a noble residence, as evidenced by decorative fragments. Most of the aquinate fortifications show interventions of scarp lining, necessary against artillery. Santoro considers the city of Cassino with its Rocca Janula, built in the 10th century and later modified, raised, and scarped in subsequent centuries, the focal point of the Benedictine lordship in the land of Saint Benedict. He finds the existence of a double defensive line: inland and at sea, the latter erected against the Saracens. The two fortress-castles of Gaeta emerge in all their importance and architectural grandeur, although both buildings have been deeply modified in recent centuries.

- The investigation by the architect Donatella Fiorani (1966) on the fortresses of Lazio started from those in the Sacco Valley, and is fundamental guide for the typology classification reported in thie presente study. The essential nature of the morphological elements is attributed to the lack of building programs, limited to the construction of modest fortresses, as the lords resided in urban palaces. This, according to Fiorani, led to limited and contingent interventions in the buildings, although the 13th and 14th centuries saw a flourishing of fortified constructions, almost all connected to the related urban centers. According to Fiorani, maturity in construction was only reached in the 14th century, without following the classic genetic typology: tower, enclosure, palace, and perimeter towers; after the 14th century, interventions are noted in few cases with the transformation of the entire defensive type. In the papal area, Fiorani found that all the towers are quadrangular, a fact already highlighted by Bascapè and Perogalli, who noted the scarcity of cylindrical towers, instead very common in the Neapolitan kingdom. Fiorani observes that the landscape presented by the fortified settlements is not typical of a border environment. The fortified architecture of Lazio essentially serves the defense of the settlement and not the creation of a network. The nature of the fortified structures in papal Southern Lazio can be inferred from the conduct of 14th-century wars, a series of trench fights between castles. Fiorani also agrees on the existence of subsystems linked to the lordships. The situation is different in the Neapolitan kingdom, where a clear design has created a network of fortifications whose buildings represent the best of medieval castle architecture. The

Fiorani, D. (1996). Tecniche costruttive murarie medievali: il Lazio meridionale (Vol. 1). L'Erma di Bretschneider, Roma

Fiorani, D. (1998). Architettura e cantiere delle strutture fortificate. In I castelli del Lazio meridionale. Contributi di storia, architettura e archeologia (pp. 55-106). Laterza.

difference between the two zones is due to the political stability that allowed the lords of the Neapolitan area to erect and strengthen massive fortified structures. The papal state's interest in castles was low, as fortresses and their owners were potential centers of rebellion. The lower constructive force in the 12th-14th centuries, which corresponded to a greater destructive impulse in the 15th-16th centuries, is the origin of the lower number of castles.

3. Geographical framework

In the current Southern Lazio, four large sub-regional areas can be identified, each with relatively homogeneous historical development and geographical characteristics:

1. Campagna and Marittima: deeply connected to the Roman region and the events of the papacy.
2. Lower Liri Valley: where the Montecassino lordship developed.
3. Gaeta and its territory: displaying characteristics of a strongly autonomous power center since the early Middle Ages [Coccia, S.].

The Lombard conquest marked the first emergence of a frontier after the Roman era, dividing territories and urban centers in the region under study. The boundary was initially established with attacks in the years 570-590 and later modified at the beginning of the 8th century when Duke Gisulf of Benevento conquered the centers of Sora, Aquino, and Arce. It is challenging to identify military construction initiatives from this turbulent historical phase and distinguish them from previous urban fortification interventions and castra in the frontier area. Hypothetical fortification initiatives include the Byzantine enclave of Gaeta and the cities of Aquino, Sora, Arpino, and Cassino.
Another significant phase of fortification interventions occurred during the Carolingian Empire's crisis in the 9th century, with increased Arab pressure prompting defensive works in urban centers and coastal sites. This period saw the construction of fortifications in Cassino (Eulogimenopoli) and the Datto Tower on the Garigliano River.

3.1 Incastellamento and settlement patterns

The incastellamento, a crucial phase in settlement history, left indelible marks on the settlement patterns of central Italy. The

presence of medieval fortifications profoundly characterizes the landscape of Southern Lazio; however, most of the structures currently preserved belong to the late medieval or early modern phases.
The main difficulty in analyzing the earliest phases lies in the total loss of early medieval structures and the first incastellamento. The transformation of fortification systems in the late Middle Ages and early modern period led to the destruction or incorporation of older structures into newer ones.
Southern Lazio is a geographically varied region characterized by pre-Apennine limestone mountain systems, intersected by the Sacco and Liri-Garigliano valleys, and the extensive Pontine coastal plain. From the east, oriented northwest-southeast, are the Simbruini and Ernici chains, separated from the Sacco valley by the Lepini, Ausoni, and Aurunci chains.
The limestone mountain range, though interrupted by the deep Sacco-Liri tectonic trench, extends to the sea with the Ausoni's extremities overlooking Terracina and the Aurunci closing off the Gaeta Gulf.
Since antiquity, the main routes connecting Lazio and Campania have been the Sacco Valley and the piedmont route running along the Lepini and Ausoni mountains' slopes overlooking the Pontine plain. This system was enhanced in Roman times with roads that partially followed natural routes, such as the Via Latina, crossing the Sacco Valley and continuing into the Liri, and others challenging geomorphological conditions, such as the Via Appia.
Most fortified sites were located in naturally protected areas, such as inland heights and coastal promontories. The study's territorial scope is confined to the provinces of Frosinone and Latina, though current territorial boundaries do not precisely match historical administrations.
While Campagna and Marittima have consistently been part of Rome and the Papal State's sphere of influence, the lower Liri Valley and the coastal territory south of Terracina have been influenced by the Montecassino lordship, the Duchy of Gaeta, the Duchy and later Principality of Benevento, the Norman Kingdom, and generally the Campanian territory.

In the territory that became the Montecassino abbey lordship, some Roman-era municipalities along the Via Latina suffered a profound crisis during the late antiquity and early medieval periods, leading to abandonment or relocation in some cases. These changes are partly attributable to their status as frontier centers between the Roman duchy and Lombard territory.

The urban centers in the lower Liri Valley were already in crisis by the time of the Lombard invasion, dating back to the imperial period. A historical-topographical examination of Southern Lazio within the medieval chronological limits reveals the presence of an extensive and articulated fortification system between Sora and Cassino, which, despite the significant fragmentation during feudalism, presents surprisingly unified characteristics (the case of the Comino Valley in the eastern castellano system, Marcello Rizzello).

3.2 Three main zones of fortified structures

In general, three zones can be identified in this part of Southern Lazio:

1. Western Coastal Zone: Fortifications here, centered around the fortress of Gaeta, aimed to repel potential incursions from the sea.
2. Intermediate Zone: Extensive fortifications controlled the Liri Valley and the routes to the coast.
3. Eastern Inland Zone: Essential for communications towards Marsica and Terra di Lavoro, concentrated in a single block and built on multiple defensive lines.

These three zones corresponded to the main access routes to the Kingdom of Naples.
The internal sector in the Middle Ages was traversed by several fundamental and ancient interconnected routes centered around the Sora road junction:

- The road from Rome through Frosinone and Veroli.
- The so-called "invasion road" from the north, through Marsica.
- The road to Cassino following the Comino Valley, then heading south and towards the coast.

The need to control these critical axes influenced the fortification work in the Sorano and Comino Valley. During the incastellamento period (10th-11th centuries), the Val di Comino and Sorano became penetration routes and sectors where diversified defensive organization plans were most clearly outlined.
Determining the number of fortresses and towers in Southern Lazio presents an initial challenge of definition. The study considers structures belonging to two provinces of the Papal State and the northern zone of the Kingdom of Naples, corresponding to part of Terra di Lavoro, using heterogeneous

and discontinuous documentary sources and a diverse bibliography in terms of disciplinary content. Despite the difficulties in dating and identifying, the study of fortified structures in Southern Lazio has the advantage of being based on architectural texts that present a largely authentic material reality. The construction site of these buildings can be inferred with an acceptable degree of approximation, and their architecture presents characteristics of definite interest.

Overall, there is a substantial change in the disposition of fortified structures in the southern Lazio territory (Fiorani D.): the northwestern margins seem to retain the distinctive characteristics of the Roman countryside, with a greater number of fortified villages, fewer fortresses, and a widespread distribution of watch and signal towers. Towards the southeast, there is a progressive decrease in towers along routes or control lines, corresponding to an increase in the presence of significant fortified fortresses.

Most fortresses are located on heights, generally not exceeding 500 meters above sea level, and in the pre-Apennine area up to 700 meters, sufficient to guarantee good surrounding control and reduce the risk of uncovered attacks.

3.3 Terra Sancti Benedicti

Fig 2. Borders of Terra S.cti Benedicti and illustration "Speculum & exemplar Christicolarum vita beatissimi patris Benedicti", 1587. (Paterna Baldizzi, 2016)

The process of incastellamento in the Cassino area began in the mid-10th century, initiated by Abbot Aligernus, who returned to Montecassino in 949. Without seeking authorization from the emperor or the Capuan princes, he constructed Rocca Janula, the castle of S. Angelo in Theodice, and the tower of S. Giorgio. Until then, the only known fortifications in the area were those of the castrum of Pontecorvo, the pretorium of Aquino, the walls of the abbey itself, and the underlying citadel of San Germano. In 967, Prince Pandolfo I Capodiferro of Capua ratified the fortifications built by Montecassino and authorized the monks to construct as many other fortifications as they deemed necessary to protect their assets.

The construction of Rocca Janula on a rock overlooking the town of San Germano was an additional fortification of the slopes of Mount Cairo, dominating the citadel of San Germano, at a time when the primary military threat came from the nearby lords of Aquino. Although the remains of the first phase of the Rocca are not preserved—the tower was certainly rebuilt in the 12th century, while the buildings currently preserved are attributable to the Frederick era—it is highly probable that the original construction consisted of a square-plan tower included in a restricted enclosure, not coinciding with the urban circuit walls, following a model found in the territory, such as on the Trocchio hill near Cassino and in Esperia.
As Delogu observed, written sources confirm that towers constitute the first elements of incastellamento, combined with castral enclosures.
In his analysis of Cassinese incastellamento, Pierre Toubert identified two types of castles: settlement castra and strategic castra, the latter with military functions like Rocca Janula. He also categorized frontier castra such as Piedimonte, Rocca di Vandra, Cocuruzzo, and Mortola, positioned along the frontier of Terra Sancti Benedicti as defined by the diplomas of the Capuan princes Landolfo I and Atenolfo II in 928.
The entry of the Normans into the scene contributed to the strengthening of these strategic castra and led to the proliferation of additional fortified sites.

3.4 The Duchy of Sora

Fig.3 Duchy of Sora (detail);. Galleria delle carte geografiche, Fresco,, Palazzi Vaticani.

Since ancient times, Sora had been a crucial gateway for access to and from the Marsica region. This role was emphasized and defined by the possession of the other two significant entrances to the Sorana Basin: Vicalvi and Isola. For this reason, it was certainly opportune for the Sorani gastaldi (Lombard officials) to occupy these two sites. In 970, Hildeprandus, son of the late Rachisio, is mentioned as both the count of Sora and Vicu Albu. Subsequently, the history of the gastaldi and counts of Sora closely intertwined with that of the counts of Marsi. It can be said that Sora's peak power in the 11th century was perhaps during its alliance with the predominant counts of Marsi, inspired by the common and necessary safeguarding of the passes of Sora and Vicalvi.
After the victory over the Hungarians, the counts of Marsi gradually occupied much of the middle Liri Valley and the Comino Valley, creating a dominion militarily stronger than that established by Montecassino. This occupation was marked by an intricate defensive system that initiated the construction of many fortresses, especially in the Comino Valley.

Despite the fragmented but numerous reports, a clear fortification plan for a vast area emerges, with certain centers considered as key nodes:

- The oppidum of **Sora** and the Castrum Vallis Soranae (Balsorano) controlled the passes of the Roveto Valley towards Marsica.
- The oppidum of **Vicalvi** controlled access to the Sorana Basin.
- Together with the castrum of S. Urbano (current Alvito), they controlled the passes towards S. Donato and Forca d'Acero.
- The castra of Atina managed the passages towards Cassino.

At the Rocca of Vicalvi, there are foundations of a tower to the east, which might date back to the 11th century, though it is difficult to attribute these structures definitively to either the counts of Marsi or those of Aquino.
The border area with the Terra of S. Benedetto appeared heavily fortified by the counts of Marsi, offering significant offensive and defensive opportunities due to its orographic characteristics.
In 1067, the Counts of Aquino began to assert their influence in the Comino Valley. That year, Adenolfo VII, son of Count Landone of Aquino, was granted the castrum with Rocca of Gallinaro, the Rocca of Cellarola, and part of the castrum of S. Urbano and Posta, where he built a residence and a fortress.

Despite the Normans, the Aquino family continued to maintain their presence in the Comino Valley. In 1087, Adenolfo of Aquino, defeated and taken prisoner by the Norman prince Gionata, sought a loan from Abbot Oderisio to pay the ransom. Oderisio agreed under specific conditions: if Adenolfo failed to repay the debt within a year, he would have to hand over the 120 families of S. Urbano under his control, excluding Monte Albeto, provided a castle was built there. The outcomes of this agreement are uncertain, but by 1096, the castrum Albeti on the mountain was documented for the first time, and two churches, S. Giovanni Evangelista and S. Simeone, were established simultaneously. At this point, the Aquino family's dominance in the valley appeared consolidated, likely shifting their policy towards Montecassino with the establishment of border fortifications similar to those of the Counts of Marsi.

3.5 The Duchy of Gaeta

Fig.4. Rizzi Zannoni, 1808, Atlas of the Kingdom of Naples, (detail); Gaeta gulf is visible in the south. Biblioteca Nazionale di Firenze.

During the 8th and early 9th centuries, Gaeta was a fortified settlement, a castrum with no institutional control over the hinterland and only a small extra-urban territory. A defensive wall protected the settlement at least since the mid-8th century, as evidenced by the register of Pope Zacharias (741-752), which mentions the lease of land outside the walls ("terram vacantem foris muros castri caetani"). After the early 9th century, the castrum gained importance and achieved the status of a civitas.

The incastellamento in the Gaeta region did not fundamentally alter the settlement pattern until the arrival of the Normans. In the early decades of the 11th century, as shown by the distribution map of sites prepared by J.F. Guiraud, casalia, curtes, and other non-fortified inhabited places were still predominant. There were only eight fortified sites in the Gaeta region at that time. From the mid-11th century, Gaeta became a target of Norman expansion, particularly under the ambitions of the Norman Count of Aversa, Richard Quarrel, who, together with his son Jordan, acquired the Principality of Capua and conquered the Duchy of Gaeta in 1063. From the 12th century onwards, documentation reflects a marked increase in the relative importance of dominant castral settlements compared to open sites.

4. Main factors shaping the fortification system in Southern Latium

Focusing on the regions under consideration, setting aside the various feudal changes in different centers, it is pertinent to concentrate on three specific topics for this period:

- Frederick II's Policy on Fortresses and Towers:

Frederick II implemented significant fortification policies during his reign, enhancing the defensive capabilities of key sites to ensure control and security over his territories. These policies included constructing and reinforcing numerous fortresses and towers, often utilizing advanced military architecture techniques.

- Policies of Charles I and Charles II of Anjou:

The Angevin rulers, Charles I and his successor Charles II, continued and expanded upon the fortification efforts initiated by Frederick II. Their policies aimed at consolidating Angevin control over the region, ensuring the loyalty of local nobility, and protecting strategic points from potential threats.

- Construction Interventions by the Aquino and Cantelmo Families:

Both the Aquino and Cantelmo families played significant roles in the construction and fortification of their respective domains. Their efforts included building new fortresses, reinforcing existing structures, and adapting fortifications to meet contemporary military needs.

4.1. The Fortification Programs of Frederick II in Terra di Lavoro

In 1220, upon being crowned Emperor of the Holy Roman Empire, Frederick II ordered the Abbot Stefano of Montecassino, who had shown hostility, to cede Rocca di Vandra and the well-fortified Atina. He also mandated the demolition of castles and towers built after 1189, affecting Montecassino in southern Lazio. Abbot Stefano complied by demolishing Rocca Janula, which suffered its third destruction. In 1229, as a new conflict between the empire and the papacy loomed, Abbot Stefano, encouraged by Frederick II, swiftly rebuilt Rocca Janula, repaired the walls of S. Germano, and fortified S. Pietro in Monastero. That same year, Frederick II, preparing for a return to the Holy Land, entrusted the castle of Piedimonte, Rocca Janula, Pontecorvo, and Castelnuovo Parano to his loyal followers, the Aquino family. Frederick II's army, commanded by Thomas of Aquino, Count of Acerra, carried out a punitive expedition against Sora for siding with the papacy, destroying it entirely. However, the Rocca on Monte S. Casto was spared for its strategic importance in controlling the passes of Roveto Valley. Despite peace treaties, Rocca Janula eventually came under the direct administration of the crown, becoming part of the Demanium Regis. Following a significant earthquake on June 1, 1231, Frederick II initiated a vast fortification program to rebuild and enhance defenses in Terra di S. Benedetto and other borderlands.

4.2. The Angevin Reorganization of fortresses and castra

Shortly after the Angevin consolidation of power, there was renewed interest in the defensive system of Terra di Lavoro's castles. On November 28, 1269, Charles I of Anjou issued orders to the officials of the Principality of Terra di Lavoro and Abruzzo for the payment of chaplains and necessary repairs to the castles. Specifically, he assigned a castellan, a squire, and twenty servants to Rocca Janula, allocating 111 ounces and 28 tari for their maintenance; for the castrum of Sorella, a knight castellan and thirty servants were assigned with 170 ounces and 10 tari. This distribution underscores Rocca's continued efficiency and strategic role despite Sora's destruction. Charles I also allocated many castles to his loyal followers to reward their fidelity and exert direct control over the territory. Significant attention was given to the passes of Sora and Isola del Liri. Sora was accorded the legal status of a city belonging to the Royal Demesne, reaffirmed by Charles II of Anjou in a privilege dated November 13, 1292, reinstating Sora in the Royal Demesne after a temporary feudal grant to Jacques Bourson.

4.3. The Fortifications of the Counts of Aquino and Cantelmo

The Counts of Aquino and their related Cantelmo family were significant builders in the Comino Valley. The construction interventions by the Counts of Aquino spanned from the 11th to the 13th centuries, while the Cantelmo family carried out extensive building projects from 1349 to the mid-15th century. In the 11th century, the construction of the Rocca of Posta and Gallinaro began, though nothing remains of Rocca di Posta except an image in the early 17th-century stuccos of Villa Gallio in Posta Fibreno. In contrast, much of the residential sector of the Rocca on Monte S. Stefano (Atina) was built after 1094 by the Counts of Aquino. The 12th-century saw fortifications at Terelle and the construction of a tower and defensive wall restoration at Vicalvi by Adenulfo, primarily for military purposes. The Cantelmo's construction activities intensified after the September 7, 1349 earthquake, which completely destroyed the village on Monte S. Stefano (Atina) and severely damaged Alvito's Rocca, killing Adenolfo III of Aquino and his family. Rostaino Cantelmo rebuilt Alvito's Rocca, transforming it from a military fortification into a more residential structure. The Rocca, as depicted in the 17th-century stuccos of Villa Gallio, was protected by a high wall with four round towers at the corners. In the early 15th century, the Cantelmo carried out significant restructuring and fortification at Vicalvi, likely adding outer protective walls and a moat, while enhancing the residential aspects. This period saw extensive military engagements, with fortifications like Vicalvi, Rocca Sorella, Alvito, and Isola di Sora playing critical roles in resisting invasions and sieges, especially with the advent of firearms and artillery. The strategic destruction of these fortifications aimed to dismantle the powerful defensive system that had formed in the Comino Valley and Sorano, marking the decline of the fortresses' overall efficiency in Terra di Lavoro.

4.4. The Decline of Fortifications and the Advent of Firearms

With the gradual introduction of firearms, the fortified systems of Alta Terra di Lavoro began to decline. Major sieges in the 15th and early 16th centuries highlighted the limitations of older fortresses, leading to significant transformations to accommodate new military technologies. For example, the 1435 siege of Vicalvi by Riccio di Montechiaro's powerful army tested the old fortifications. In

1528, a significant French army besieged Vicalvi, which had been modernized with artillery positions, and the fortress withstood the siege for several months. In 1496, after the French of Charles VIII abandoned the kingdom, the Cantelmo continued the fight against the Aragons, with Rocca Sorella under the command of humanist warrior Mario Equicola, who refused to surrender despite orders from Giampaolo Cantelmo. The widespread use of firearms and mining in the 15th-16th centuries led to extensive structural changes, such as adding sloped bases to fortifications, exemplified by the towers of Civitavecchia, Campoli, and Carpello (Campoli Appennino). Significant renovations at Vicalvi, Alvito, Rocca Sorella, and Picinisco's fortified palace were undertaken to enhance defenses and accommodate artillery. In summary, while the strategic fortifications built by the Aquino and Cantelmo families initially provided strong defenses, the advent of firearms and changing military tactics ultimately led to their decline and transformation in the early modern period.

5. Overall classification of fortresses in Southern Lazio

The need to classify the fortresses through a repertoire of all information has stimulated the creation of a database on the fortresses and towers of Southern Lazio in GIS. Territorial organization is one of the most relevant aspects as it measures the functionality of the defensive system.

Key Steps:

- Survey of existing medieval fortifications in Southern Lazio collected in GIS
- History of settlements and architectural analysis of some representative cases
- Cataloging (genesis, territorial distribution, morphology)
- HBim Modelling

Considering the two state partitions that this portion of Southern Lazio found itself in during the Middle Ages and the plurality of feudal systems, we can trace back the genesis of the castles, their morphology, and the reasons for their current condition. The origins of the fortresses can be attributed to local lordships, functional to the feudal policy. Where the lord rarely inhabited the fortress (typically in the papal area), the structure tends to be smaller. In contrast, where power needed to be represented in its grandeur and the lord resided in the fortress for extended periods (as in the areas belonging to the Kingdom of the South), the fortress assumed larger proportions and a more decorated appearance. Key observations to the fore in these fortifications include: extensive use of irregular stone masonry, which turns out mainly with many variations depending on local conditions and ways of building. The layout of fortifications relates to dynamics related to a changing frontier, particularly about military strategy, nature of threats, and methods of defense employed overtime. Besides being a defensive structure, these represent very important features in the determination of settlement patterns and, as a matter of fact, clear indicators of the hierarchical status of the settlements around them.

Relationship between fortress and town in Southern Lazio

The relationship between fortresse and its town can take many forms and express both functional and symbolic links Sometimes, the fortress is strategically fitted into the urban tissue, becoming a centerpiece within the town's defensive structure that influences the towns spatial organization. Whereas in other cases, this fortress is isolated, on high ground or even far from the inhabited hub, constituting a protective outpost and symbol of authority at one and the same time. These differing configurations make clear the manifold roles that fortifications played in relation to the settlements they guarded, shaping not only their defensive strategies but also their social and political dynamics.

- Strong military connotation and reduced residential vocation: one example is Rocca Janula, Rocca d'Arce, and Roccaguglielma, which are separate from and overlooking the urban core. Their relationship with the town highlights the defense and control role of the fortified structure. This fortified garrison-town relationship is rare in the rest of Southern Lazio, but examples include the fortifications of Pisco Montano and Rocca Sorella above Sora, near the southern internal border.

- Fortifications located at the highest point of the town: Examples include Castelnuovo Parano and Fratte, Pico and Colle S. Magno in the Cassino area, Vicalvi, Alvito, Civitavecchia di Arpino to the southeast, Sermoneta, Maenza, Terracina, Itri, and Spigno towards the coast, and Paliano, Piglio, Trevi nel Lazio, Torre Cajetani, Morolo, Fumone, Veroli, Pofi, and Arnara.

- No altimetric hierarchy between the fortress and the town: lost, and an attempt is made to create a buffer zone, which serves as additional defense for the inhabitants and the fortress itself, hindering potential assaults by the population. This occurs in Collepardo, Porciano, Piombinara, and Ninfa. Sometimes, the terrain morphology provides such separation, as seen in Aquino and Pontecorvo.

- <u>Fortress integrated into the town without discontinuity:</u> as seen in Fondi, Cisterna, Ceccano, Montefortino (now Artena), Sgurgola, and S. Lorenzo in Valle (now Amaseno).

Typological aspects of Lower Lazio fortifications

Lower Lazio displays a variety of fortifications' types, because of their various historical, social, and military functions. Representative types include homogeneous castrum – a structure with no defenses due to projections but mainly a fortified village – normally serving both in defense function and as a settlement nucleus for the local community. Another important category is the residential castle of feudal lords, which unites a defensive fortress with the dwelling place of the nobility. Such examples include Sermoneta, Ninfa, and Maenza. Besides their purely defensive purposes, these buildings were also status symbols for the feudal nobility. This category includes castles with a keep, where the fortified structure is more modest in residential capacity, giving more importance to defense than to habitation, as in Colle S. Magno and Roccaguglielma. These types of fortifications illustrate both the different functions of the fortification itself concerning the diversification of the defensive strategies and social hierarchies of the region.

Many structures were demolished during the Middle Ages, primarily due to the common practice of reusing construction materials. This procedure was often triggered by traumatic events such as war assaults and especially seismic events, notably the violent earthquake of 1349 [R. Motta 25]. The Second World War caused significant damage, particularly in the Cassino area and along the coast. Noteworthy examples include the enclosure and tower of Rocca Janula, the tower of Settefrati, and the tower of Pandolfo Capodiferro near the mouth of the Garigliano River.

The Fortresses: Case Studies, Location, Typology, Functions

Approximately sixty existing structures in Lower Lazio can be defined as fortresses. A typological classification can only be based on the layout and internal functional organization. The scarcity of studies on the construction phases prevents a definitive understanding of the buildings' configurations over time. There are no thorough archival researches shedding light on modern transformations, no archaeological excavations, and the study of the masonry is often lacking reliable surveys.

A. Fortress-Tower

B. Fortress with Enclosure, Tower, and Secondary Buildings: These are complexes consisting of enclosures with more or less regular profiles, with buildings and usually a tower positioned centrally (keep) or along one of the sides of the enclosure (e.g., Torre Astura, Rocca Janula, Supino). The tower stands out compared to other structures, ensuring control and defense of the territory. It is based on a square or pentagonal base, while the enclosure takes on heterogeneous shapes, linked to the terrain's morphology (triangular, square, irregular polygons). A notable feature is their specific functional and defensive peculiarities.

C. Fortress with Enclosure, Tower, and Residential Buildings: These residentially purposed fortresses are primarily located in fortified village centers, serving as baronial residences and architectural landmarks.

D. Fortress with Elongated Enclosure and Residential Buildings: This category includes complexes with heterogeneous structures, with or without a keep or other towers. The distinctive feature is the presence of an extended enclosure, usually elongated and matching the site's morphology, allowing for a large parade ground within the structure (e.g., Roccaguglielma, Castelnuovo Parano, Spigno, Pico, Roccasecca, Vicalvi).

E. Fortress with Enclosure, Tower, and Palace: (e.g., Alvito, a fortress with a quadrangular enclosure with circular towers and a beautiful palatial structure, now unfortunately in an advanced state of decay, reminiscent of solutions adopted at Monte S. Giovanni Campano).

F. Two-Component Fortress: Consisting of two separate structures, one composed of a cubic base and a circular tower (e.g., Fondi).

G. Fortress-Palace

H. Compact Structure Fortress: (e.g., Castel Mattia, Pofi, Porciano, Maenza, Traetto, Gaeta).

Gaeta is a unique case in Southern Lazio, featuring two adjacent and interconnected fortresses and buildings comparable to the largest fortifications in the Kingdom of Naples. Expanded and substantially rebuilt in the post-medieval period, the complex consists of two quadrilateral structures with circular towers at the corners (the lower one incorporating the Angevin core, the upper one entirely Aragonese). Gaeta serves as a prime example of the homogenization of medieval pre-existing structures, mainly in response to new defensive requirements introduced by firearms.

It is interesting to note how different the fortification types' geographical distributions are, with respect to the historical and political boundaries of Southern Lazio. Elongated enclosure fortresses and fortress-towers are predominantly inserted within the territories of the former Kingdom of Naples, reflecting the region's specific defensive needs and architectural traditions. Instead, fortress-palaces and two-component fortresses are more typical within the Papal State, where these fortifications often acted as the military and administrative focus and hence as symbols both of defense and government. Whereas these types reveal a quite clear geographical preference, other typologies of fortification are distributed more equitably across the region, reflecting varied defensive strategies in response to local conditions and events over time. [Fiorani D., 1989]

6. Criteria for the selection of the cases of study

The selection of case studies for testing the procedure was based on several considerations to come up with diverse examples of fortification. Among these, the type of fortification and its condition and availability of documentation ranked high. The type is the first criterion-according to the design and purpose-which enables us to include quite a few structures running from military strongholds to border fortresses, each bearing different architectural and functional features. Referring to the type classification given in the previous paragraph, Rocca Janula was chosen for type "Fortress with enclosure, tower, and secondary building"; Alvito for type "Fortress with enclosure, tower, and palace"; Vicalvi for type "Fortress with elongated enclosure and residential buildings", Gaeta for type "Compact structure fortress", and Sora for the fortress type with elongated enclosure. Integrity and authenticity are important aspects that inform about the condition of these structures. Those fortifications with low level of integrity, with their most parts damaged, result in need for restoration or rehabilitation interventions. The authenticity level was also taked into account, in regard to the degree to which the original material and form are preserved without major changes over the years. Furthermore, the selection considers the maintenance state with regard to evaluating efforts taken to its preservation.

Thus, this criterion can give a view of the attention each site has received and relates it to their present situation. It might be added that the ownership of a site-whether public or private-allows any difference in the level of access possible, in-depth study, and preservation.

The regularity or lack of it, which may be obtained in the fortification plan, is directly related to the degree of architectural difficulty and strategic consideration by its builders. This was also important for determining the degree of adaptation and for designing based on topography or needs at a particular time. Finally, the documentation availability, which was considered scarce for most of the fortifications taken under considerationo. Sites are classified as good, which refers to survey, graphics, documents, and studies; discrete, referring to graphics and documents; poor, only written documents; and none, meaning only toponym levels of documentation. These criteria allowed the research, in turn, to reach a representative and balanced selection of fortifications allowing insight into their architectural, historical, and cultural value within the limitation of their state at present and available resources.

VI

CASES OF STUDY

PAPERS

BOARDS

Graphic elaboration by the author

View of San Casto castle, photo taken by drone by the author in collaboration with engineer Marco Saccucci.

Fig.1 Depiction of the "Terra di Lavoro Olim Campania Felix," Fabio Magini, 1620, detail of the Middle Valley area .

1. San Casto Castle, Sora

Perched above the city of Sora, at the summit of Mount San Casto, approximately 500 meters above sea level, stands the formidable "Rocca Sorella," dedicated to Saints Casto and Cassio. This impregnable fortress has withstood the test of time—resisting earthquakes, wind, and the ravages of centuries—remaining a proud symbol of a historic frontier: the gateway to Abruzzo. The Castle of San Casto and Cassio is undeniably one of the most significant landmarks in military architecture within the Southern Lazio, despite its current state of ruin. The sheer size of the structure speaks to the former prominence of Sora itself.

From the era of the Volsci, through the Romans, the Lombards, and finally to Frederick II—who, despite waging war against Sora and destroying the city, failed to conquer the castle—the fortress played a pivotal role in the region's history. Later, it came under the control of noble families such as the Della Rovere, the Cantelmo, and finally Carrara, who restored it and gave the fortress its current form—partly visible and partly left to the imagination of today's visitors and hikers. Unfortunately, due to the neglect by various political authorities over the years, Rocca Sorella now lies in ruin atop Mount San Casto.

1.1 Historical documentary survey

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, 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 history of Rocca Sorella dates back to the 6th century BC. Initially a stronghold of the Volsci, it later became a Roman and then a Lombard possession. In the 13th century, it was damaged by the forces of Frederick II but was subsequently restored. The castle passed then to noble families, such as the Cantelmo, Della Rovere, and Boncompagni, who defended it against rival armies. At the turn of the 16th century, the lands of Sora drew the attention of Cesare Borgia, known as "Il Valentino." Funded by his father, Borgia sought to expand his holdings and repel foreign forces from the Papal States. One of Pope Alexander VI's, Cesare's father, goals was to reintegrate Sora into the Papal territories, viewing it as a key fief to reclaim, following the 1472 agreement brokered by Pope Sixtus IV Della Rovere.
Though primarily a military stronghold, the arx civitatis nostrae Sorae briefly took on a residential role, hosting prominent figures such as the young Duke Francesco Maria I and his mother, Giovanna Feltria of Montefeltro. However, it wasn't until 1520 that the castle underwent its most significant reconstruction. Under the patronage of the Della Rovere family, Evangelista da Carrara from Bergamo redesigned the medieval fortress, modernizing it to meet the evolving demands of warfare. The reputation of this impregnable fortress quickly spread, becoming a point of interest in the field of military engineering.

The castle was part of a larger network of fortifications, evidenced by the remnants of two semicircular watchtowers that can still be seen on the ascent to the site. In the 15th century, a second defensive line incorporated the Aragonese Tower near the Cathedral of Santa Maria.
It is characterized by the presence of six towers (polygonal, square, and cylindrical), each strategically designed to adapt to the natural features of the mountain terrain.

1.2 Evolutionary hypothesis

The hypothetical historical evolution of the fortress is described in three main phases (as shown in board 2). The architectural layout presents a first early medieval nucleus, most likely surrounded by square 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, 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.

1.3 Georeferenciation in GIS

The geolocalization of the castle of San Casto in the database FortLiriGIS (as shown in Board 3) highlighted how the Sorano Castle was a historical fulcrum of a defensive system around which satellite fortresses were articulated.

1.4 Geometric-material survey

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 guarantee at least 50% overlapping of images. The alignment of frames in the post-processing 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

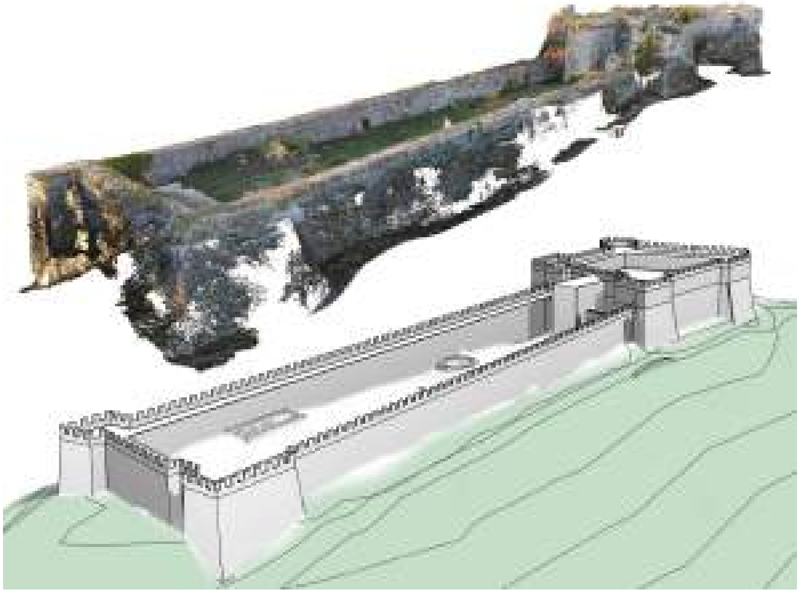

Fig.2 Elaboration by the author of the HBIM model based on the digital reconstruction.

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. (See boards 4 and 4b)

1.5 HBIM for three-dimensional ontological modelling

The accurate digital reconstruction allowed the development of a H-BIM 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).

Fig.3 3D digital model from UAV survey of San Casto castle, in Sora. Geometric analysis of the bastion. (Elaboration by the author)

1.6 Further analysis

The accurate digital reconstruction allowed the development of a H-BIM 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).

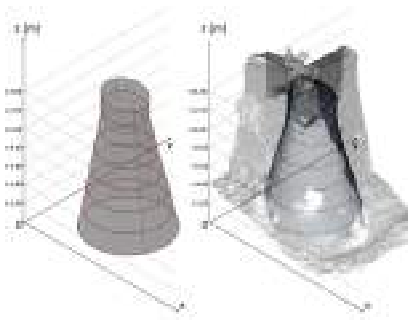

Fig. 4 Geometric model and empirical model: Cross-sections (Elaboration by the author)

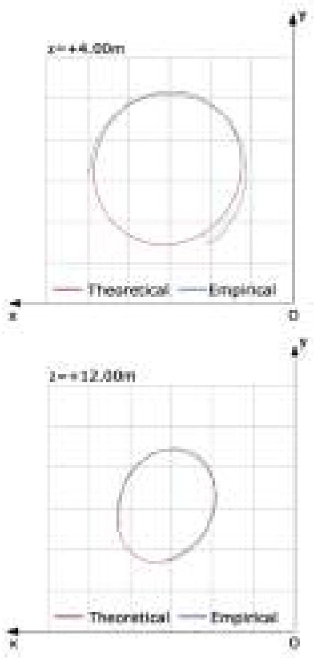

Fig.5 Comparison of the theoretic and empirical sections: analysis of deformation. (Elaboration by the author)

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. The procedure is applied on the only one circular tower remaining of the San Casto castle.

The procedure is developed in two stages. The first 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 of the time. The second phase, based on the digital survey, models the state of the art, returning the real geometry, which could contain any discrepancies with respect to the geometric/ theoretical model.

To understand the reliability of the theoretical model, the cross-sections and longitudinal sections were performed on the geometric model and then on the point cloud with the free Cloud software. 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, allowing the comparison between the two models, theoretical and empirical, of the tower.

The overlapping of the sections taken from the theoretical model and the empirical one showed a typical tendency of the cylindrical structures, called "ovalization," giving a qualitative analysis of the deformation.

SfM technologies are of great help both in enhancing the existing building heritage and in the increasingly accurate and complex analyses required by the current time.

The 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 to appreciate any deviations between the two geometries but also to intercept any structural deformations. The identified procedure is relatively fast, inexpensive, and requires limited manual processing. Future developments concern the 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. The procedure is applied on the castle of San Casto and in the other fortified structures of the apparatus, the defensive system of southern Lazio, selected for this research.

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Typology	
Typo	Castle
Name	San Casto castle, or Rocca Sorella
Property	Public owner - municipality
Localization	
Municipality	Sora, (FR)
Elevation	539 mt asl
Coordinates	41.7167 N - 13.6167 E
Consistency	
Surface	2700 ca m^2
Volume	7600 ca m^3
Masonry	Opera incerta - local calacarenite
Scarp	Yes
Conservation Values	
State of conservation	Abandoned/ Medium
Integrity	Low
Authenticity	High
Historical Significance	High relevance

Cartographic references:
a| CTR Comune di Sora, Foglio 10. Scala 1:5000, anno 1994;
b|Drone sequence of architectural emergency (property of the author)


a

Fondo Antiguo de la Biblioteca de la Universidad de Sevilla, España

c


d

IV sec — Foundation of the castle by Volsci. Polygonal walls to defend against Sabines, Hernians and Marsics

III sec — Roman settlement (Tito Livio in Arx sorana)

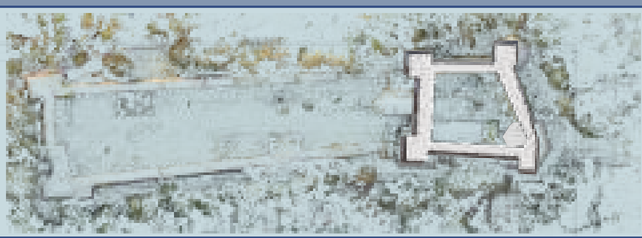
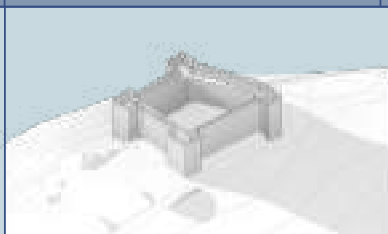
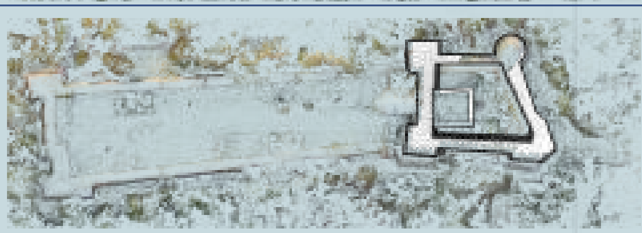
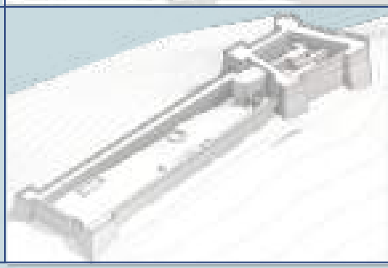
0

XIII sec — Partially damaged during the battle between Fedrick II and Papal State. It was rebuilt soon together with other castle forming the defensive system of the Kingdoom of Naples

XV sec — Reconquered by Cesare Borgia, son of Pope Alexander VI

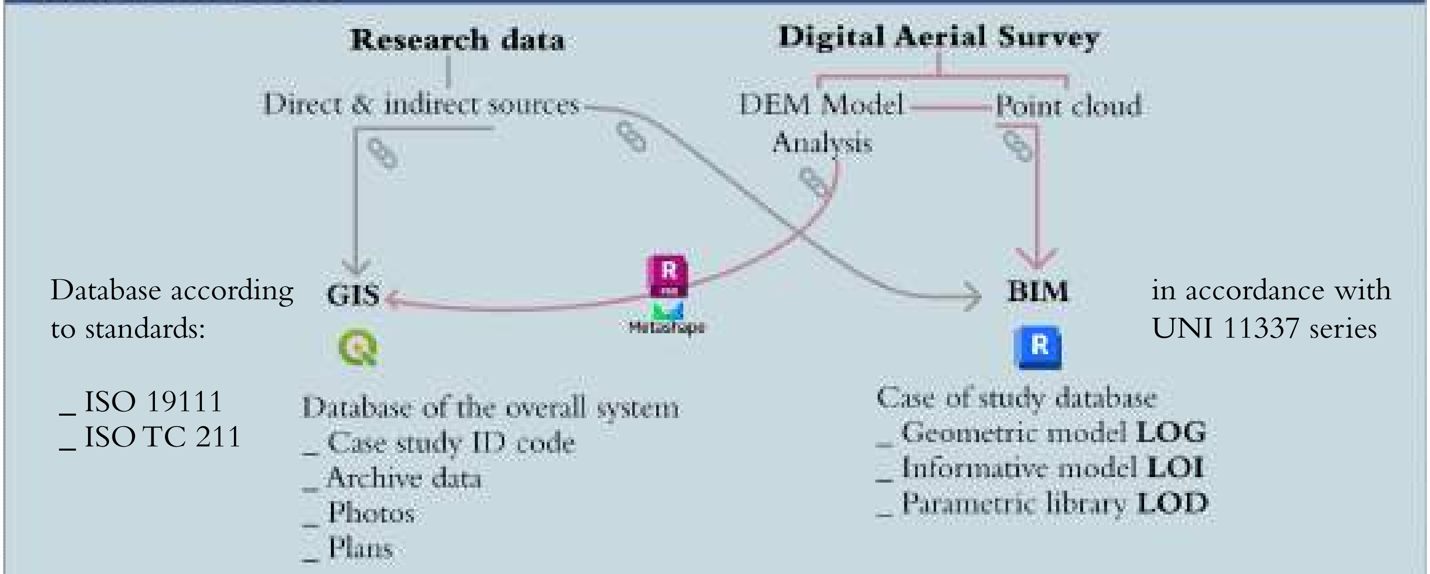
1520 — Duck Guillaume De Croy restructuring with the present appearance as a residence.

XX sec — Abadoned

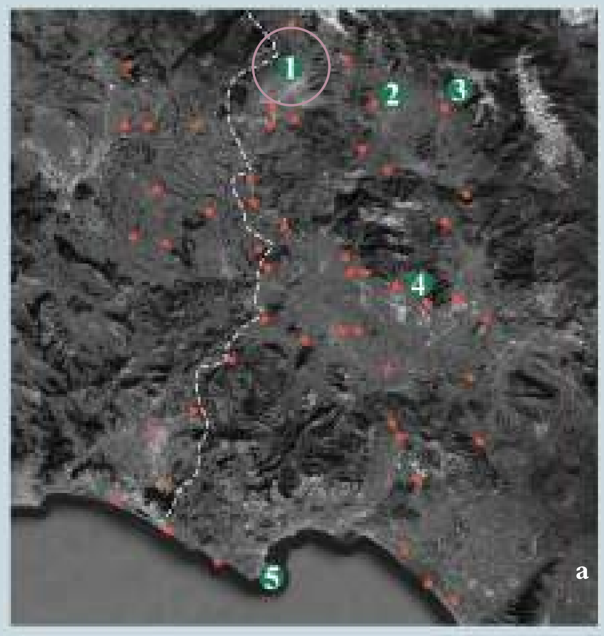
	DIGITAL PHOTOGRAMMETRIC MODEL	DIGITAL GEOMETRIC MODEL	
XI Century			The original core has a typical fortress layout. It is developed on an irregular quadrangle with square medieval towers.
XIII Century			In the 13th century, as in most Latium fortifications, a central keep was added.
XV Century			During the Renaissance period, the castle, which became a residence is greatly enlarged, and a cistern and chapel are inserted inside.

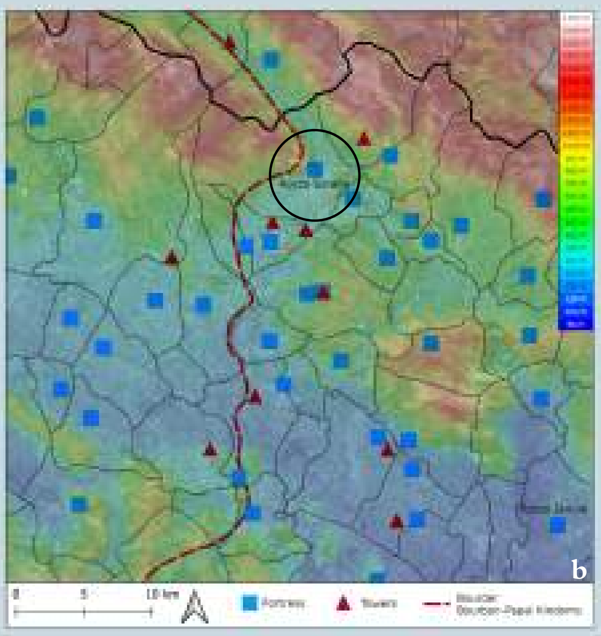
References:
a | Oil on canva, Sora view (1601-1605), Vanni F., Santa Maria degli Angeli, Sora; **b |** High relief in stucco, Sora bird's eye perspective, (1613), Viscogliosi Castle; **c |** Engraving on paper, City of Sora, (1700 ca), Pacichelli, G. B. Naples; **d |** Cadastrial map of Sora, 1900.

DATA STRUCTURE



GIS fortresses database

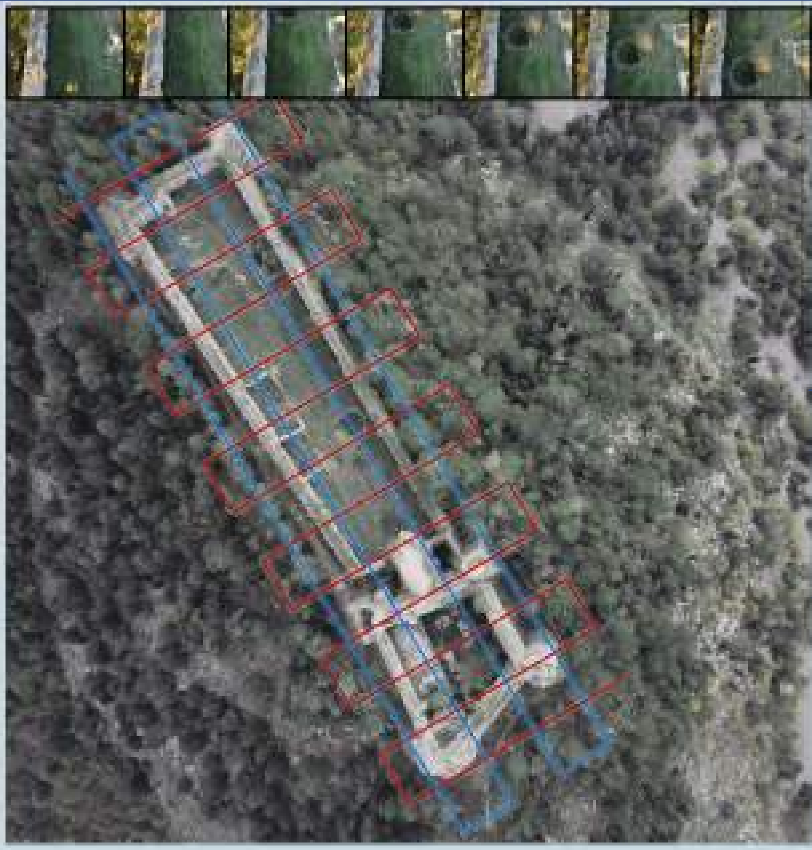




Maps are georeferenced in WGS84 UTM32N (EPSG 4326)
a | Case study identification with ID code, San Casto Castle is represented by "01"
b | GIS symbolically shows the consistency of the fortification phenomenon and the orography of the terrain.

GIS shaft of fortified architecture in southern Lazio and informed case study schedules

Flight plan



Report

Drone DJI Mini 2

Path n.1

Path n.2

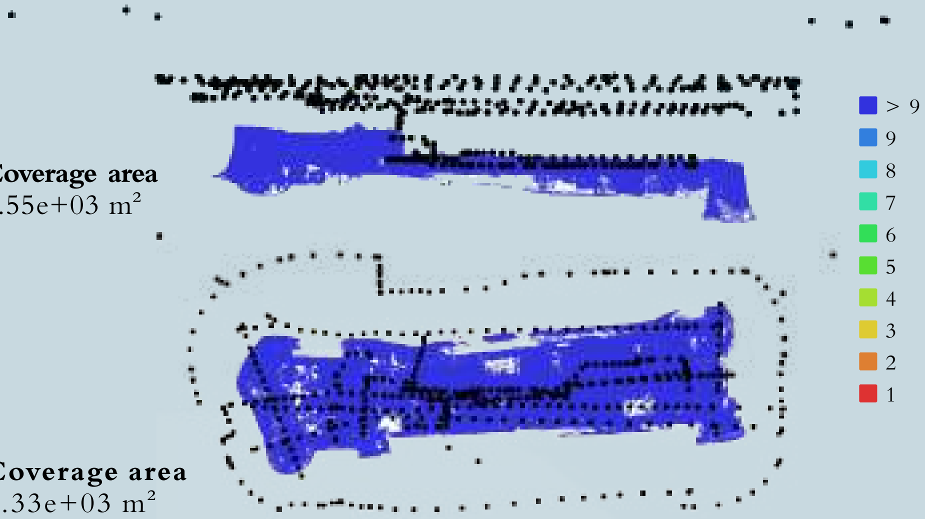
Date 20.11.2021
Time 15:00-18:00

Number of images:	581
Flying altitude:	32 m
Ground resolution:	7.51 mm/pix

Camera stations:	558
Tie points:	307,736
Projections:	1,156,347
Reprojection error:	0.703 pix

Survey Data

Camera locations and image overlap.



Coverage area
1.55e+03 m²

Coverage area
4.33e+03 m²

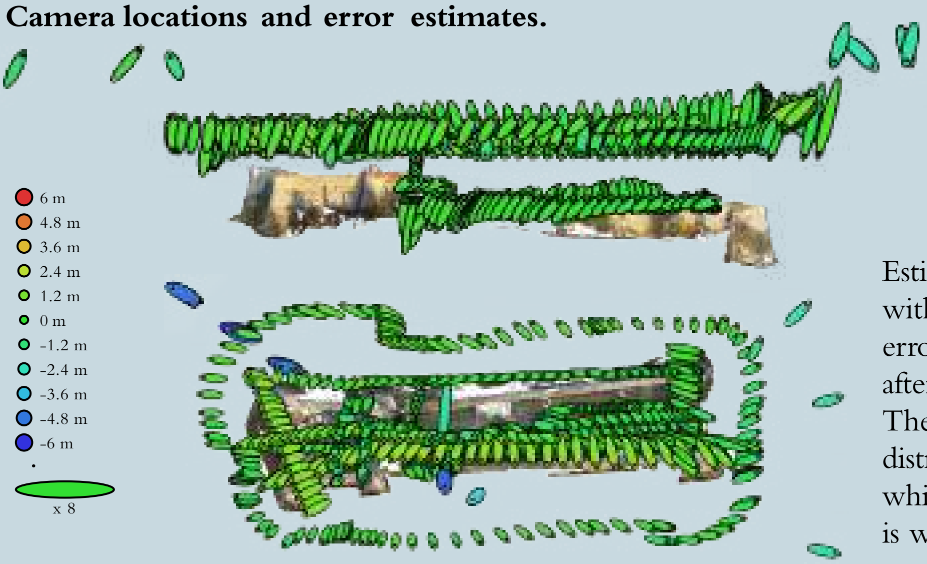
Camera Model
FC7303 (4.49 mm)

Resolution
4000 x 3000

Focal length
4.49 mm

Camera Locations

Camera locations and error estimates.



X error (m) 0.420154
Y error (m) 0.658807
Z error (m) 1.04909
XY error (m) 0.781381

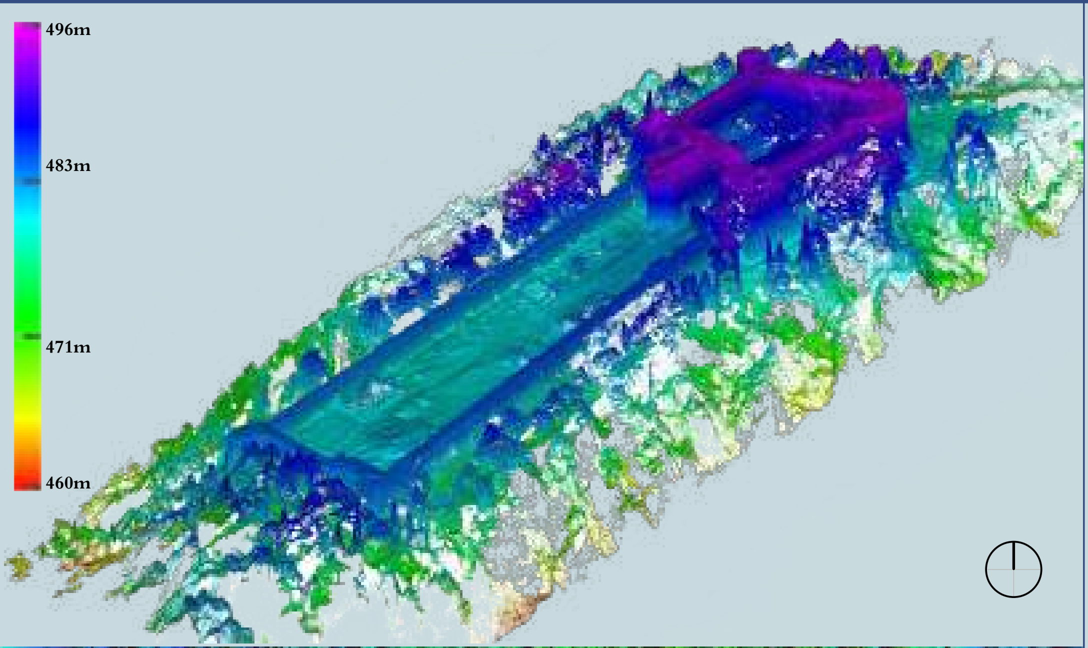
Total error (m)
1.30811

Estimated camera locations are marked with a black dot. Ellipses represent the error related to the cameras positioning after the resolution of the SfM process. The total error is the probability of distribution of the cumulative error, which here is less than 1%. The survey is well performed.

01

Digital Survey

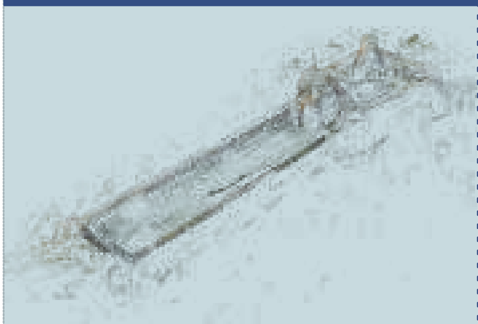
DEM_Digital Elevation Model



Stereo image pairs from an image collection are used to generate a point cloud representing the 3D locations for each of the connection points extracted from the images for which elevation data can be derived.

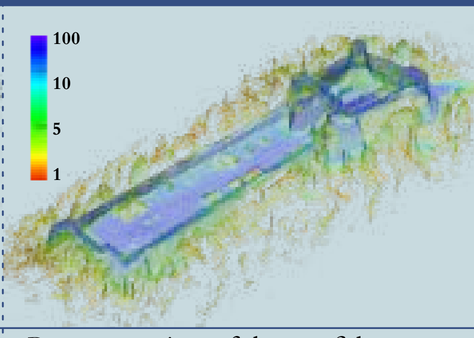
The derived elevation data can be visualized in a digital terrain model (DTM), which includes an estimate of the ground surface, and a digital surface model (DSM), which includes elevations of above-ground features.

Sparse cloud point



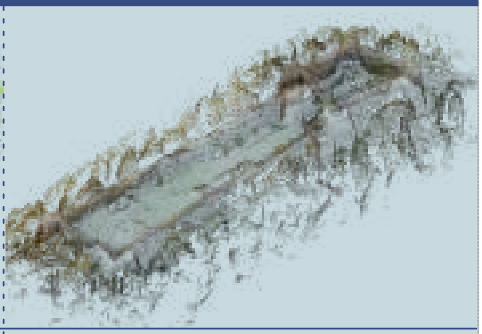
Key points resulting from the Structure from Motion process of camera alignment. First alignment step: the result is a sparse point cloud.

Confidence factor



Representation of the confidence factor, which indicates from how many frames the photogrammetry software records information and how accurate it is. Blue indicates the most accurate value (100%)

Dense cloud



The dense cloud is characterized by a high density of points, providing a highly detailed and accurate spatial distribution of the features. It is the basis for creating 3D models and analyses.

Tiled model

EST

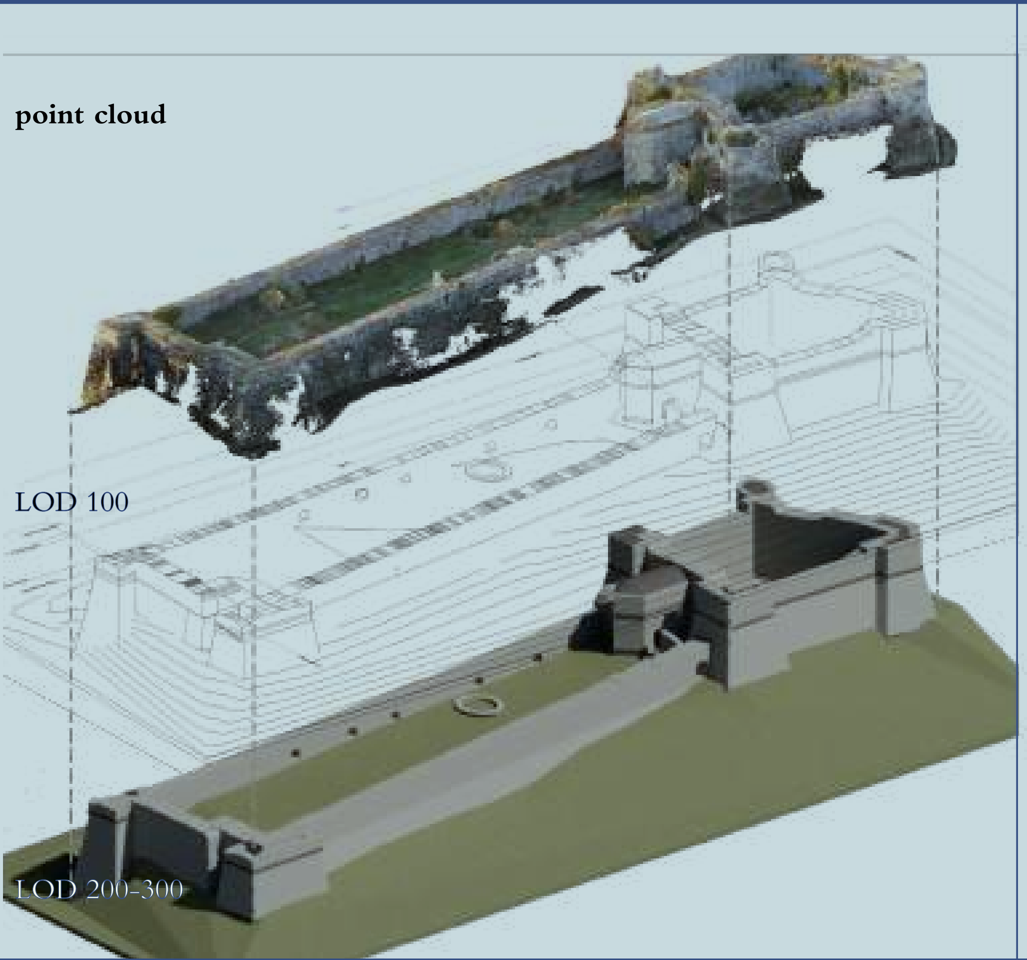
SOUTH

WEST

NORTH

The tile model is based on a dense point cloud and represents a high resolution, large-scale 3D model visualization. Its hierarchical tiles are derived from the original images, providing more information about the texture of the masonry.

SCAN TO BIM Procedure



INPUT

point cloud
.rcp file

point cloud
.rvt file

LINK

Rocca Sorella .rvt file

Architectural model

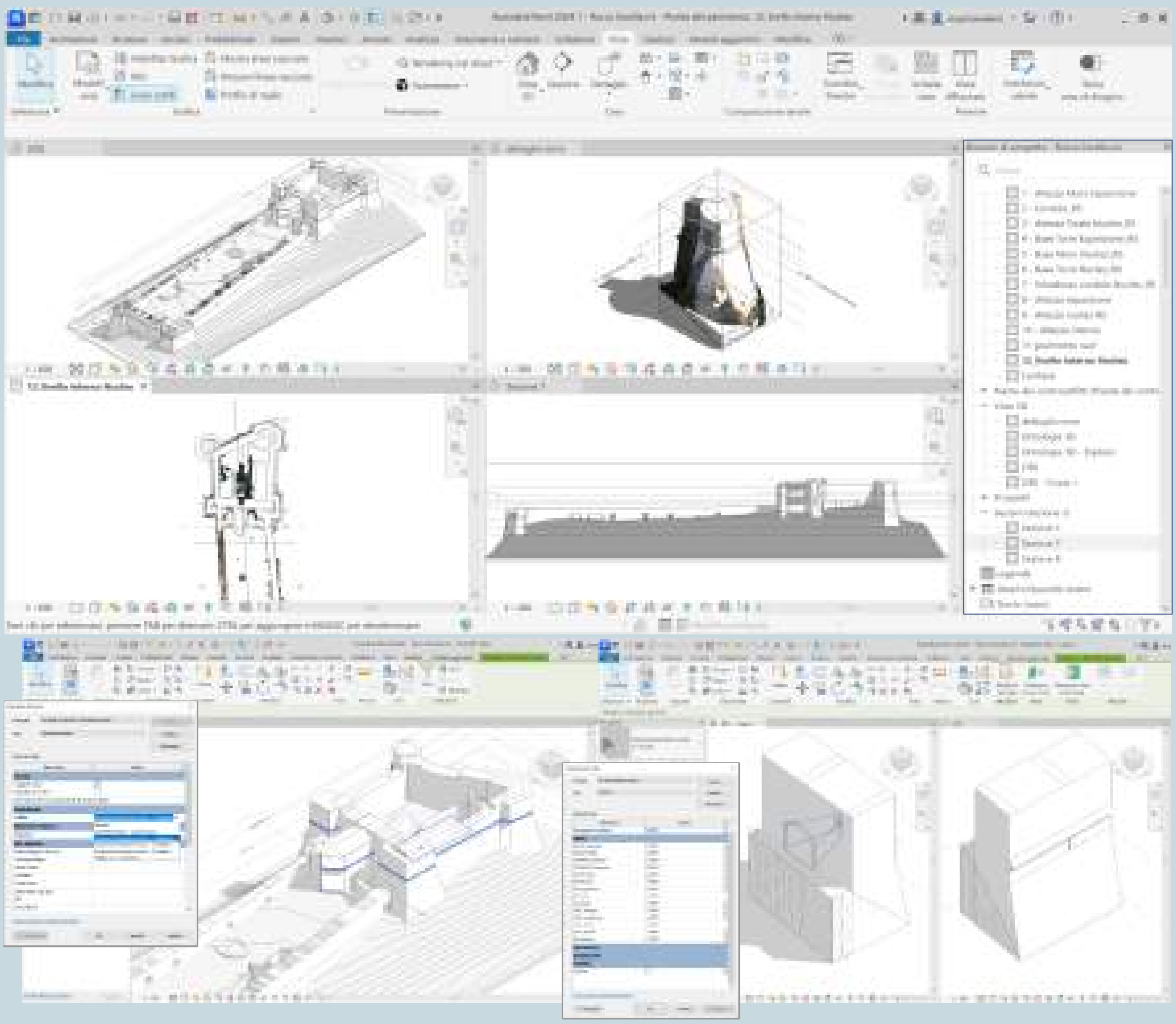
Features

(low)	(high)
LOG &LOI	LOG &LOI
Plugin in Revit	Revit families

OUTPUT

Structural Analysis	HBIM model

HBIM Parametric Modeling



_Definition of levels and design grids

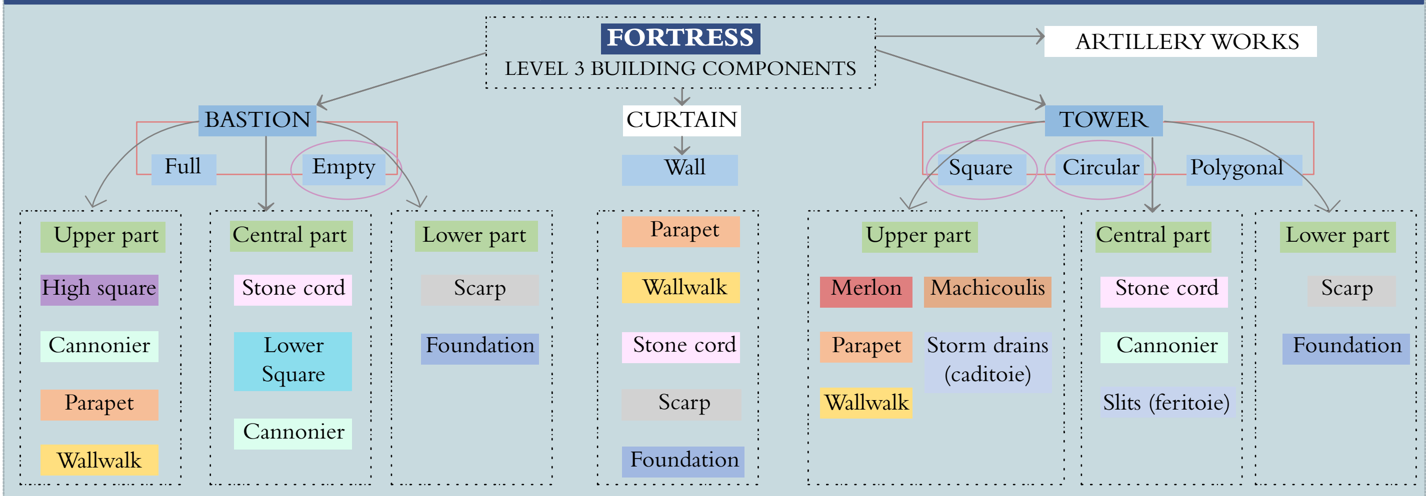
_Definition of design attributes (walls, floors, roofs)

_Modeling according to the point cloud: elaboration of the state of the art

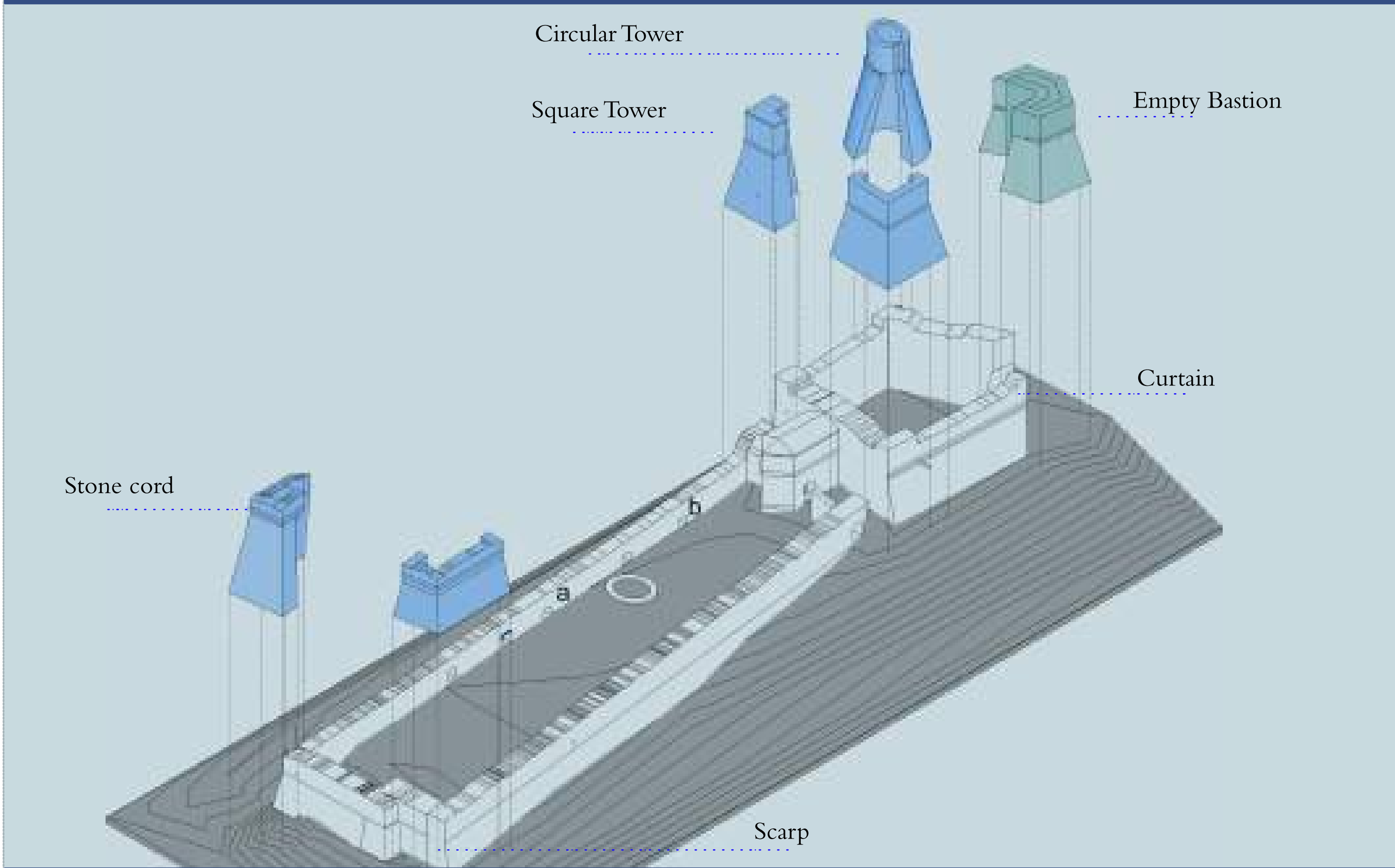
_Material and structural information of "wall, roof, floor" objects

_Modeling of local parametric families

Semantic segmentation and ontology construction (WBS)



Semantic enrichment of the HBIM model



Glossary extract - LOI

Arquebusier: slit cut in the walls to target attackers without exposing oneself, firing with blunderbusses. Depending on its specific use it was called: archer, crossbow and arquebusier, composite slits allowed the use of two or three different weapons.

Curb (or Stone cord): architectural expedient adopted on the outside of parapets or battlements to prevent slipping or ricocheting of projectiles launched from below.

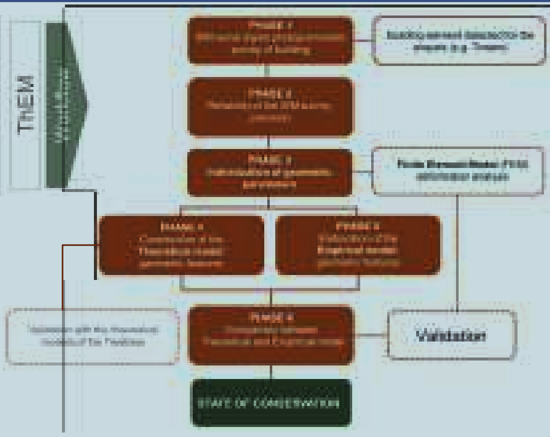
Cortina: Part of the wall between two successive towers or bastions. Essential element of any fortification, as it establishes the perimeter that must be defended.

Tower, (tour, Fr.) any high build ing raised above another, consisting of several stories, usually of a round form, though sometimes square or polygonal: a fortress, a citadel.

Tower-bastions: in fortification, are small towers made in the form of batstions with rooms or cellars underneath to place men and guns in them.

Scarp: moat wall along the city wall or wall addition sloping at the base of the walls, to strengthen them and nullify the dead angles in front, to prevent the approach of mobile towers and the danger of mines.

THEM WORKFLOW | PHASE 1: SfM survey - identification of the architectural elements

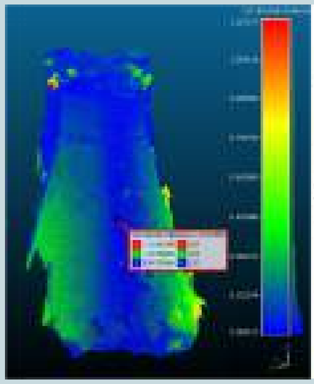


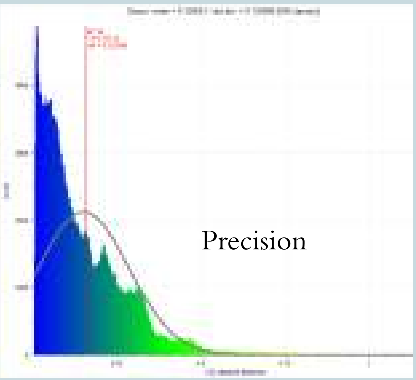
Survey A	
Date	06.09.2022
Time	10.00-12.00
Points n.	6,421,009
Frame n.	1107
Frame size	3000x4000
Height of fly	30m

Survey B	
Date	04.04.2023
Time	11.30-13.30
Points n.	7,342,659
Frame n.	1182
Frame size	3000x4000
Height of fly	30m

PHASE 2: Reliability of SfM survey and Precision

Alignment





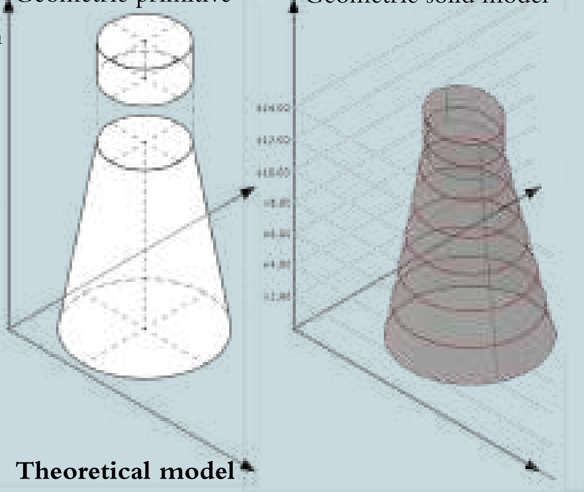
Precision

Definition and construction of the models. PHASE 3: Theoretical model and Empirical models

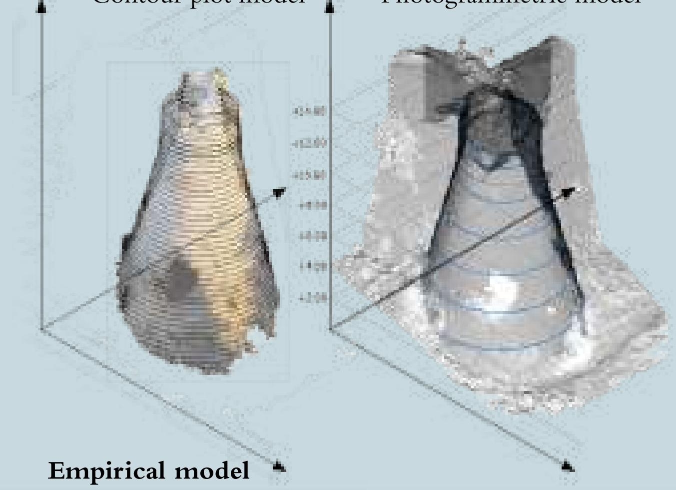
_ Individuation of the geometric parameters

_ Construction of the theoritical model

_Analysis of the empirical model

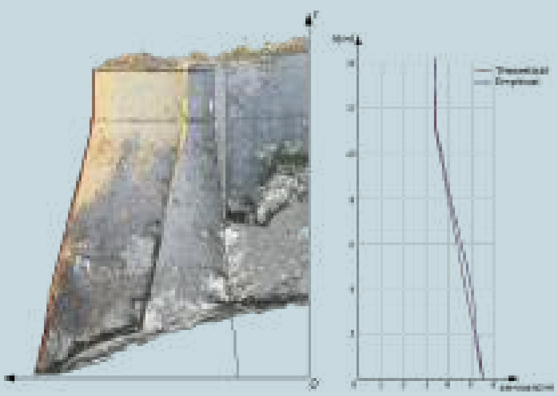


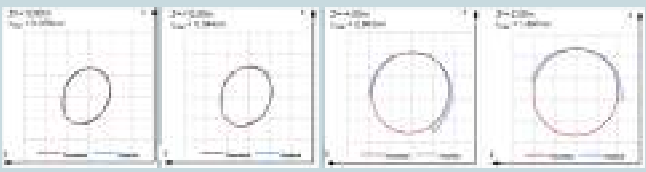
Theoretical model



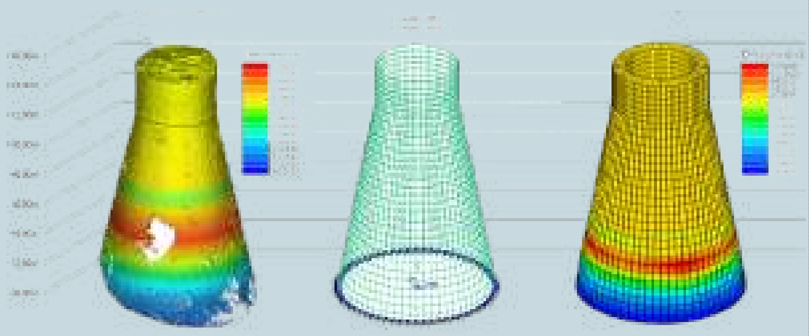
Empirical model

Comparison between the models and results





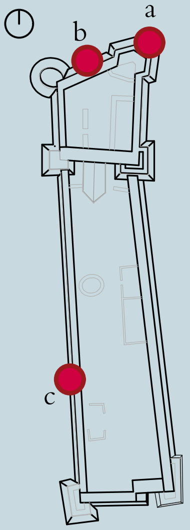
Validation of the procedure

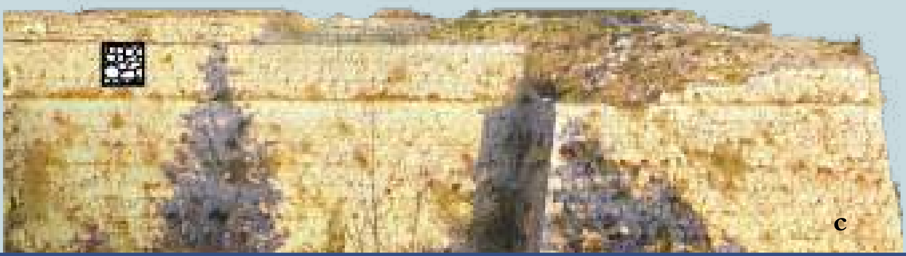


ThEM analysis | Mesh model | FEM model

Reference: Pelliccio, A., Saccucci, M., & **Miele, V.** (2023). Deformations of the Fortress Towers Analyzed by the SfM Survey. Nexus Network Journal, 25(Suppl 1), 39-46.

Samples identification for masonry analysis

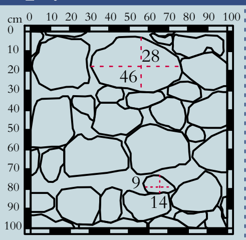




Masonry consisting of natural resistant elements.

Masonry consists of stone elements bonded together by mortar. Stones obtained by felling rocks are laid in irregular layers of uneven thickness, bonded by mortar.

empty bastion (a)

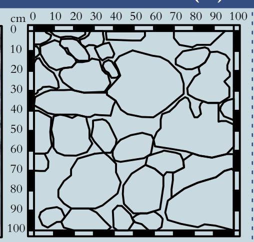


	STONE	MORTAR
Area [m2]	0,8166	0,1834
Area [mm2]	816600	183400
%	81,7	18,3
Ratio Mortar/Stone	0,224	

Ratio solid-void: 0,22%

The stone used is local calcarenite, in uncertain work with stone inserts of fair size but in good condition. the sample affects the first core of the castle.

curtain wall (b)

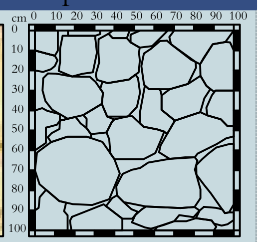


	STONE	MORTAR
Area [m2]	0,8184	0,1816
Area [mm2]	818400	181600
%	81,8	18,2
Ratio Mortar/Stone		0,222

Ratio solid-void: 0,22%

The stone used is local calcarenite, in uncertain work with stone inserts of fair size but in good condition. the sample affects the first core of the castle.

Scheda di campione di



	STONE	MORTAR
Area [m2]	0,8960	0,1040
Area [mm2]	896000	104000
%	89,6	10,4
Ratio Mortar/Stone		0,116

Ratio solid-void: 0,12%

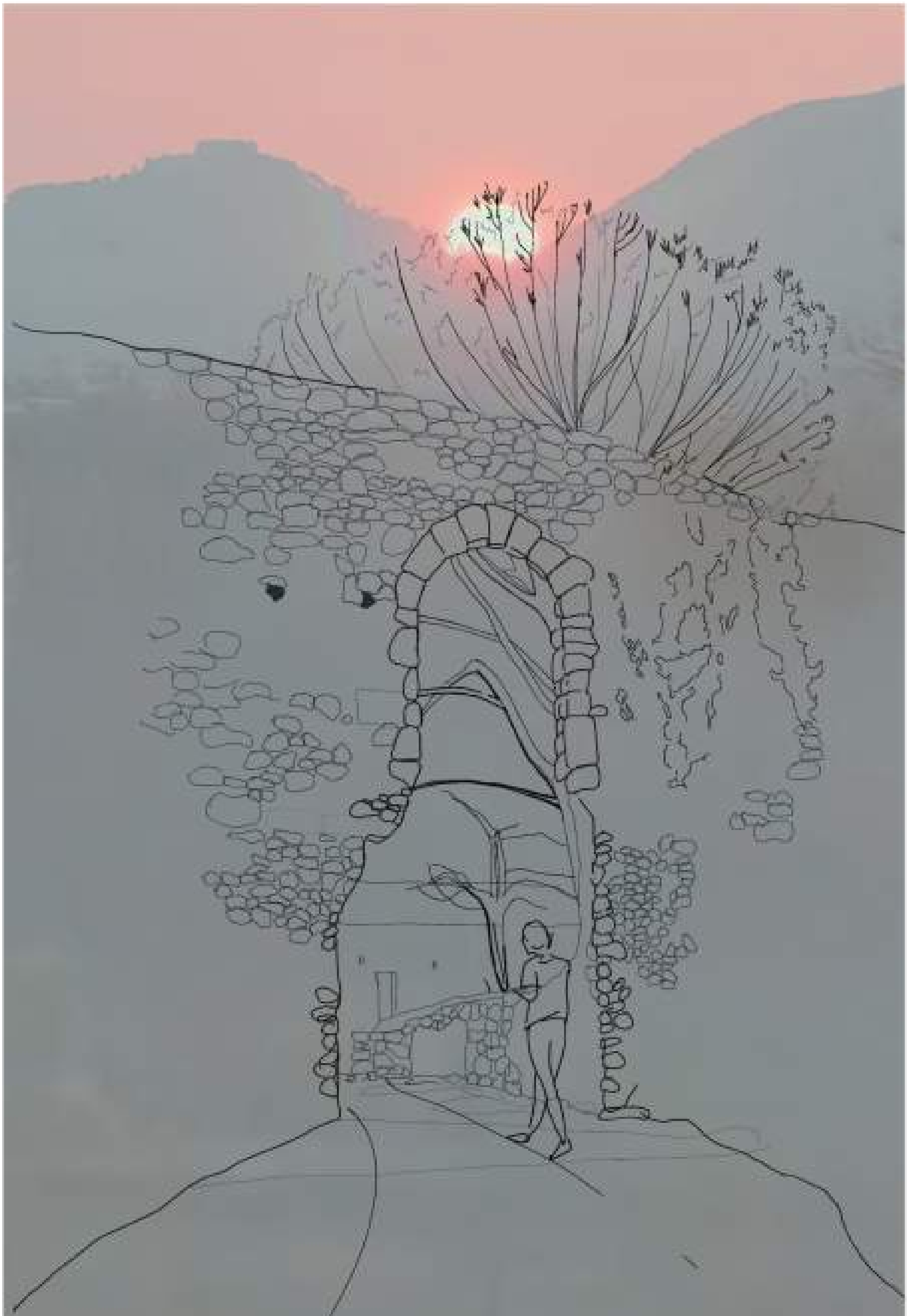
The stone used is local calcarenite, in uncertain work with stone inserts of fair size but in good condition. the sample affects the expansion of the fortress along the ridge of the mountain.

Synthesis Masonry features

	Material	Characteristics	Dimensions
Stone block	Lithology Sedimentary rock clastic (local calcarenite)	Superficial processing - roughing - squaring Color -Yellowish; - grey Shape - irregular	Block (hxb) min: 9x14 cm max: 46x28 cm
	Mortar composition	Morphology and surface finish:	Thickness
Joint	aerial lime mortar (?)	-indented - degraded	Horizontal 3 - 30mm Vertical 3 - 10mm
Texture	Opera incerta		
Section	Nucleus undetected	Sack masonry	Total thickness 2m Nucleus: n.r
Description	Masonry with two faces occasionally connected with through elements (diatons) Made of local stone foundations, of small and large size, set to opera incerta with earth bedding and repointing		

Sample sheet of masonry technique. References to current standards for the parameters components of the sheet:

_NTC 2018 (Technical standards of construction)
_CIRCOLARE 21 gennaio 2019 , n. 7 C.S.LL.PP



Graphic elaboration by the author

View of Vicalvi castle, photo taken by drone by the author in collaboration with engineer Marco Saccucci.

Fig.6 Provincia di Terra di Lavoro, Attilio Zuccagni Orlandini, 1844, Firenze, (detail) (Vicalvi, Alvito and Sora visibile on the north), geographical atlas of the Italian states

2. Vicalvi castle

The case of Vicalvi is representative of the Rocche casuistry with elongated enclosure and residential bodies. the different rooms are arranged along almost the entire length of the innermost enclosure. the building grew through distinct construction phases, protracted from the 13th to the 14th century.

2.1 Historical documentary survey

The hill on which the historic center of Vicalvi stands is an isolated spur of Lower Cretaceous limestone. The summit, occupied by the castle and the medieval village, of which significant remains still exist, reaches an altitude of 580 meters. The hill is separated by a deep valley with a strong karstic character that divides it to the North from Monte Morrone (1005 meters) and Colle Terelle (1055 meters); to the South-West, quaternary formations extend between Vicalvi and Fontechiari. The village of Vicalvi developed on the top of an isolated hill. The elevation begins with a flat area to the east, ranging from 555 to 570 metres, followed by a higher part to the west (where the castle was built in the Middle Ages), reaching a maximum height of 592 metres, which would be the probable Arx. The hill of Vicalvi has different heights on different ridges: the northern ridge is the steepest, with heights ranging from 101 metres to 74 metres; the western ridge, also very steep, but partly terraced, has a height difference of about 70 metres; the southern ridge, softer and terraced, both due to landslides and human intervention, has a height difference of 228 metres; finally, the eastern ridge descends to the plain.

Beyond Via Sferracavalli lies another hill, on which stands the ancient Convent of San Francesco. The masonry circuit consists of a first part made of polygonal work of the first manner, formed by large barely hewn blocks. Towards the northwest and west, its traces are lost, making it improbable that the masonry circuit was open. Particularly on the west side, it can be assumed that it was replaced by later fortifications to protect the western side of the hill and have a curvilinear course of the wall circuit. To the east, the fortifications distributed along a curvature with more angles, likely having the only still-existing opening. To the south, the masonry circuit probably developed in an amoeboid shape. The period of most intense development is certainly between the 6th and 4th centuries BC. The dating of the masonry circuit to the 5th-4th centuries BC is supported by various pre-Roman ceramic finds and the construction technique of the first and second manners used for much of it. It can thus be hypothesized that the first settlement was a village called Cominium between the 7th and 8th centuries BC, indicating strong ties with the Volscian phase.

2.2 Evolutionary hypothesis

The most important historical period occurred in 1702 with the conquest by the Lombards, who had already occupied Aquino and Atina. In the same year, they took Sora, Arpino, and Arce, thus extending the borders of the Duchy of Benevento at the expense of the Roman Duchy. With the Lombards' conversion to Catholicism, the Benedictines initiated a slow action of repopulation and land organization through the foundation of small monasteries. However, this initiative was thwarted by the Saracen invasion, which for decades, until 1815, looted and damaged everything. This flow was favored by the territory's depopulation, due to Saracen raids and the brief Hungarian invasion of 838. The first phase of fortification occurred under the delegation of Abbot Aligerno, aiming to rebuild the destroyed churches, construct new ones, and recolonize the area, initially protecting them with a simple walled enclosure reinforced by towers, remnants of which can still be seen today. This program was continued by his successors. The importance that Vicalvi assumed over time was evident from the continuous donations received by Montecassino around 867 from Pandolfo I and Landolfo III, authorizing the construction of as many castles and towers as needed. Subsequent donations included two lakes later unified into the current lake of Posta Fibreno. Around the same time, the people of Vicalvi purchased land from Abbot Aligerno to build a castle, an agreement made in 876 before the judge Adelmondo. The group of homines (men) of Vicalvi consisted of 10 men with certain social and economic relevance. They wanted to build a castle integrated into a context of residences that also served as fortifications; it was an attempt by a community to create a work rather than a feudal lord or ecclesiastical authorities. The foundation of the castrum (fortress) went ahead despite suspensive clauses since in 1014, Emperor Henry granted Montecassino two castles in the Comino territory, Vicalvi and Sant'Urbano. Between 1000-1005, Oderisius appears as the lord of Vicalvi castle, but over the years, Montecassino's rights over Vicalvi became increasingly extensive, evidenced by subsequent donations. In one from 1064, Baldwin of Vicalvi is mentioned along with the lake, part of the same property, but shortly after, Abbot Desiderio separated them in an exchange act. In its early period, the Vicalvi fortification had a strategic role connected to its location (barbarian invasions), serving as a military stronghold, considered a refuge from barbarian invasions for Benedictine nuns, San Nicandro friars, and the population. The Castrum Vicalvese, indeed, was situated on a height in a dominant position, at the entrance to the Comino Valley and controlling the road that, passing through San Donato, led to the Forca d'Acero pass. Together with the nearby Alvito castle, it formed a difficult-to-surmount defensive block. Although its military function was predominant in the early years, the castle's presence implied a connection with the area's economic system. It was a center for various economic activities conducted in the territory, especially agriculture. The first family to inhabit the castle was the D'Aquino family; later, the Cantelmo family took over the castle, indicating that the economic situation of Vicalvi's feudal lords was improving. It reached its peak with the French-origin families Etendard and Cantelmo, under whom a residential stronghold was created, providing a satisfactory living standard for the times, evidenced by architectural interventions on the castle itself: the grace of the capitals and bifores, frescoes, monumental chimneys, water drainage pipes, and a latrine—a novelty for those times.

In the 15th century, however, the turmoil of wars restored the castle's strategic role, at the expense of the building's architectural aspect, sacrificed for military needs. The beginning of the castle's slow decline was marked by the Cantelmo family's decision to move to the nearby Alvito castle. Scarce economic resources led the Duke of Alvito to sell the castle to the Celli family, who, to prevent the castle from being entirely lost given its condition, ceded it to the Municipality of Vicalvi, which could access state funds for various restoration and reclamation works.

2.3 Georeferenced Cataloging in GIS

The use of Geographic Information Systems allows the fortification areas of Southern Lazio to be spatially documented. By georeferencing the cataloguing of architectural remains, topographic information, and historical maps, one arrives at a common spatial framework for unified analysis. GIS technology not only pinpoints the exact location of each fortification but also helps in understanding territorial dynamics, access paths, and visibility, which played key roles in their strategic placement. This georeferenced catalog serves as a foundation for further research, allowing comparisons between various fortified sites and regions. The third table shows the identification code attributed to the case study in the GIS database; the identification of the borders between the valleys, which makes it possible to understand the strategic position on which the castle is located; finally, the radii of influence between the main fortresses of Sora, Alvito and Vicalvi are shown.

2.4 Geometric-Material Survey

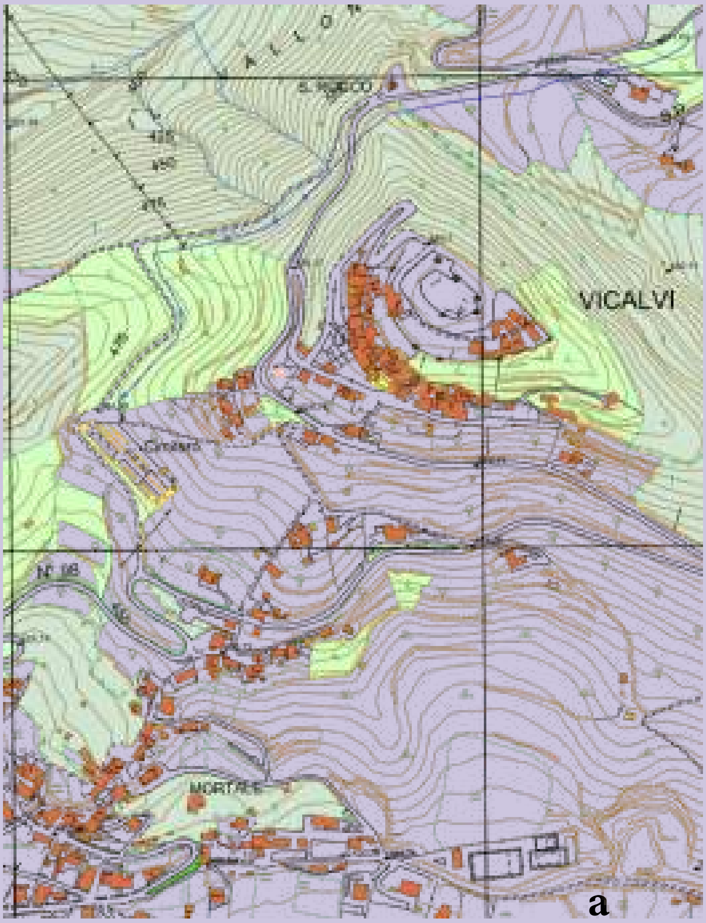
A key aspect of the documentation process is the geometric-material survey, which aims to accurately capture the fortifications' physical features. This survey involves examining the dimensions, materials, and construction methods used in the structures. It combines traditional measurement techniques with advanced tools such as drone photogrammetry to generate high-resolution data. This ensures the detailed documentation of architectural elements, serving as a foundation for digital modeling and further analysis. Photogrammetry allows for creating a very detailed digital model of the fortifications. Drone-based photogrammetry specifically provides recording that otherwise would not have been feasible, guaranteeing the completeness of the recording of the site. Using Structure from Motion techniques, sets of images taken are being processed to realize three-dimensional digital reconstructions that preserve the geometric accuracy of a site and enable detailed visual analysis. These models are vital for understanding both the fortifications' current state and their original appearance, contributing to the development of restoration and conservation strategies. The models and the results are reported in boards 4, 4b.

2.5 Three-Dimensional ontological modeling HBIM

The last phase is the realization of an ontological three-dimensional model through HBIM, in which the data acquired through geometric-material surveying and photogrammetric modeling are integrated into a fully functional digital model. This framework allows historical, material, and construction data within the HBIM to provide not only architectural analysis but also the possibility of simulating different restoration scenarios. This model acts like a dynamic tool for the researcher, wherein understanding is refined in a continuous manner as more data becomes available and further studies are conducted. The results are visibile in boards 5, 6.

2.6. Furthre analysis

The first series of processes executed, together with the results organized in spatial and architectural databases, constitute a first base for deeper analyses. In particular, the GIS database allows for spatial analyses to be performed, becoming an extraordinary basis for the understanding of territorial dynamics and relationships between sites. Moreover, as was highlighted in Chapter 4, Paragraph 7, the application of SfM techniques enables dimensional analysis. This approach has been demonstrated as providing not only accurate volumetric modeling but also potential structural indications, as seen in Tables 7 and 7b. The results would demonstrate that SfM has the potential to contribute to discussions on the construction method and stability of the structures studied, extending its utility well beyond documentation to encompass diagnostic capabilities.



Typology	
Typo	Castle; fortress with elongated enclosure and residential blocks
Name	Vicalvi castle
Property	Public owner - municipality
Localization	
Municipality	Vicalvi, (FR)
Elevation	590 mt asl
Coordinates	41.6947 N - 13.7439 E
Consistency	
Surface	ca m^2
Volume	ca m^3
Masonry	Opera incerta - local calacarenite
Scarp	Yes
Conservation Values	
State of conservation	Abandoned
Integrity	Low
Authenticity	High
Historical Significance	High relevance

Cartographic references:
a| CTR Comune di Vicalvi, Foglio 391091, Scala 1:5000, anno 2020, Geoportale Regionale Lazio;
b|Drone sequence of architectural emergency (property of the author)

0 — First a Lombard possession, with princes of Capua, the fort came into the possession of Monte Cassino in 1017.

1017 — Montecassino held it until the early 13th century, when it passed to the d'Aquino family, which strengthened its fortification, encircling it with a double ring of walls.

XIII sec — After a brief succession, in the possession, between the Étendards and the counts of Aquino, the castle passed to the Cantelmo family, who choosing the castle of Alvito as their home, decreed its sudden abandonment

XVI sec

1654 — Damages after a strong earthquake. Despoiled of ornamental stones by the population

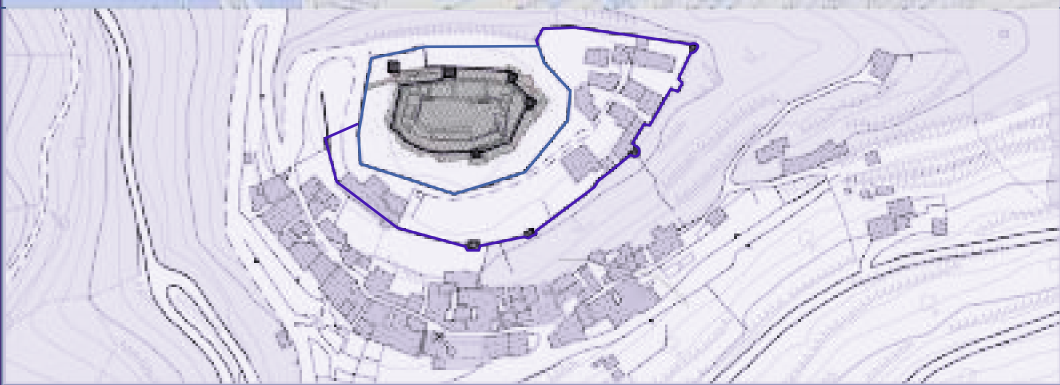
XIX sec — The Duke of Alvito, in the early 19th century, decided to cede it to the Celli family.

XX sec — Used as a military hospital during World War II and then abandoned

XI Century

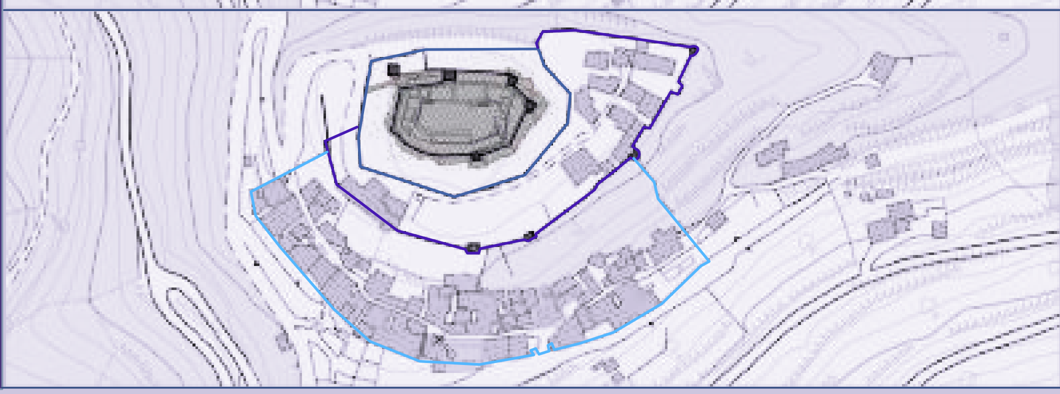
The remains allow evidence of the earliest phases of fortification to pre-Roman times, specifically the fifth or fourth century B.C., where the earliest documents attesting to the presence of the castle are from 937.

XIII Century



The residential body was added to the military stronghold, and a first polygonal wall wes added

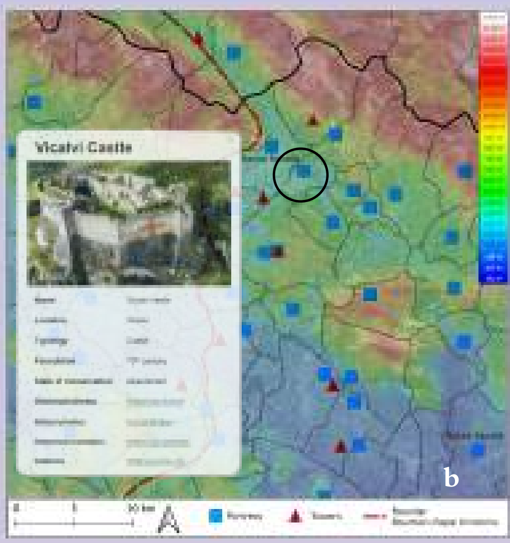
XV Century



During the Renaissance period, the castle, which became a residence is greatly enlarged, and a cistern and chapel are inserted inside; and a second polygonal wall was added.

References:
a | High relief in stucco, Vicalvi view (1633- 1660 ca),Villa Gallio, Posta Fibreno; **b |**

GIS fortresses database

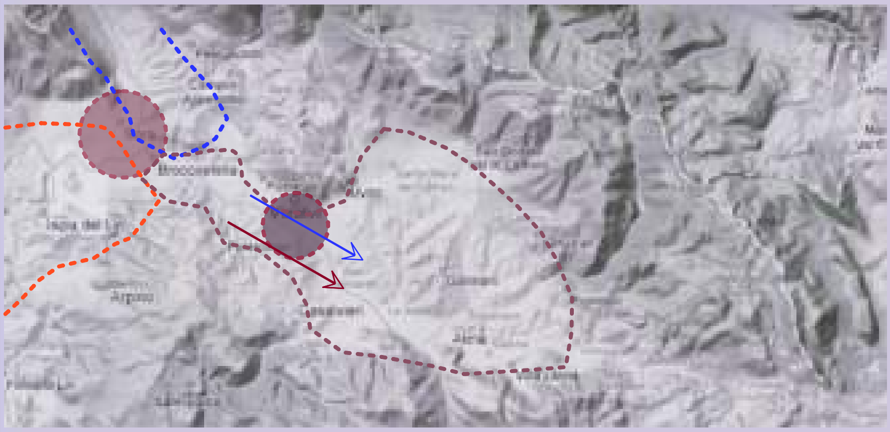


Maps are georeferenced in WGS84 UTM32N (EPSG 4326)

a | Case study identification with ID code, Vicalvi Castle is represented by "02"

b | GIS symbolically shows the consistency of the fortification phenomenon and the orography of the terrain.

GIS | Valleys identification



Liri Valley

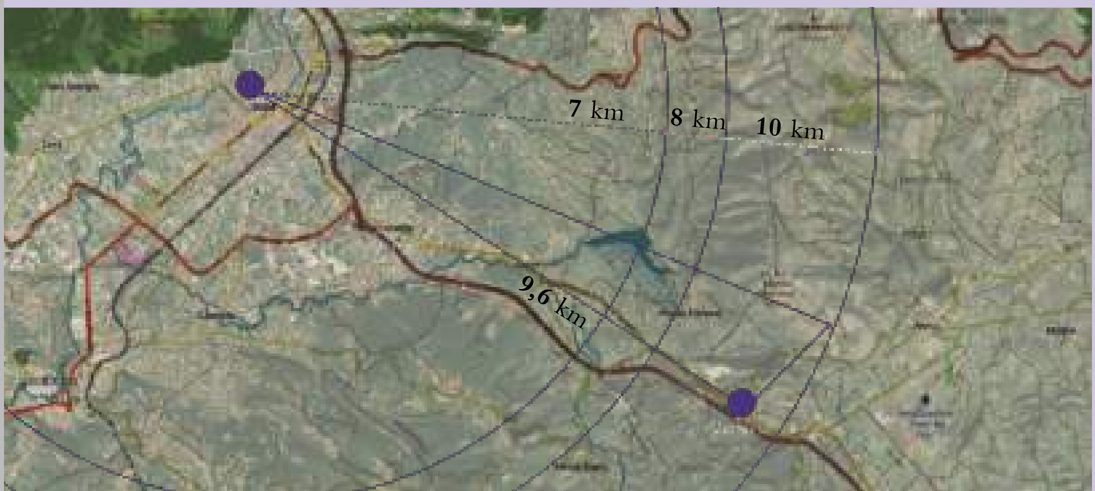
Comino Valley

Roveto Valley

Main route - between Albeto Mount (Vicalvi) and the mountain

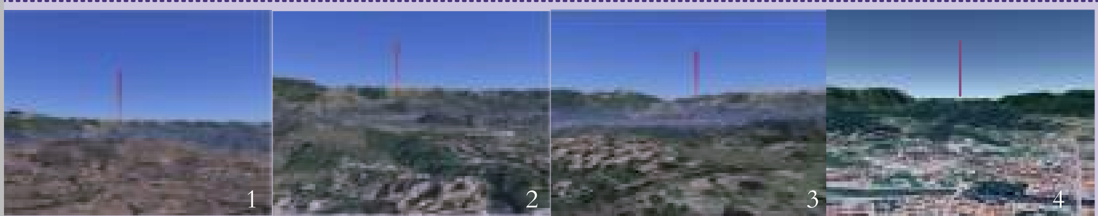
Main Valley route from north west - Vicalvi castle is strategically positioned to control the surrounding territory and trade routes. It constitutes the main gate to pass through

GIS | Influence rays between Sora and Vicalvi - Fortifications intervisibility



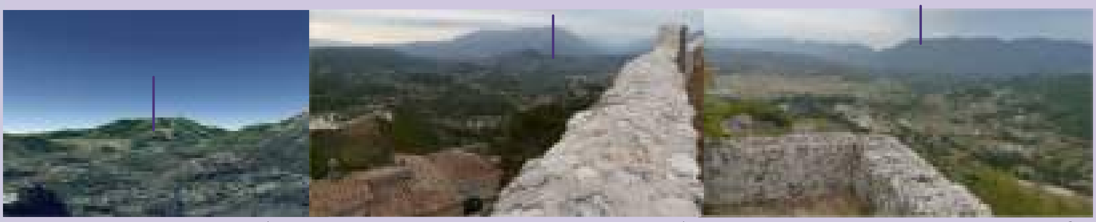
GIS analysis applied to fortifications in Latium makes it possible to understand the interaction dynamics between fortified structures and the surrounding territory. This integrated approach is crucial for understanding historical geography and territorial organisation. Intervisibility constituted the system's functionality, and today, the premise for ad hoc routes.

SORA



Sora Castle is the fulcrum of the defence system, as it for its position could control over the sourranded forts; it is visibile Vicalvi (4),

VICALVI



1 1a 2

1, 1a | To west the castle controls Roveto Valley, Fibreno Valley, and communicates with Sora Castle; 2 | To east controls over the Comino Valley, and the Atina ravine, connection with Cassino.

Flight plan

Report

Drone DJI Mini 2

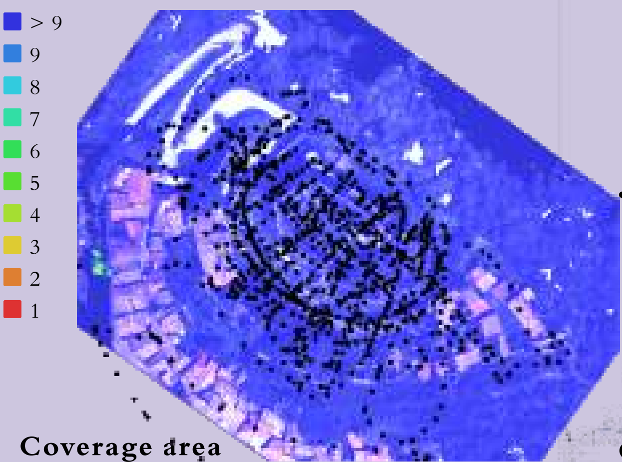
Date 20.05.2022
Time 10:00-13:00

Number of images:	1,107
Flying altitude:	67.3 m
Ground resolution:	1.45 cm/pix

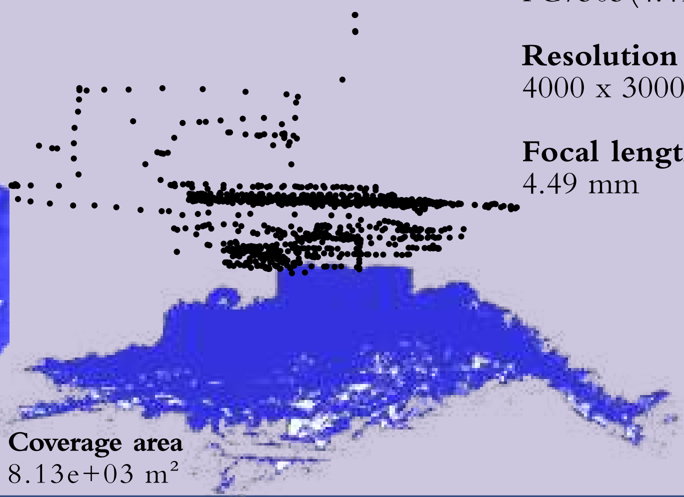
Camera stations:	1,104
Tie points:	508,182
Projections:	3,328,620
Reprojection error:	1.25 pix

Survey Data

Camera locations and image overlap.



Coverage area
0.0529 km²



Coverage area
8.13e+03 m²

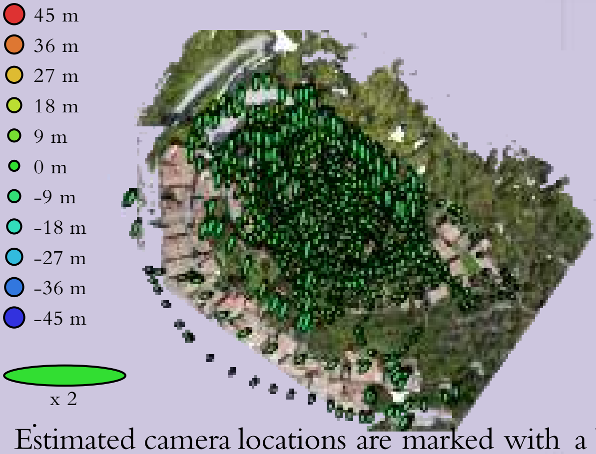
Camera Model
FC7303 (4.49 mm)

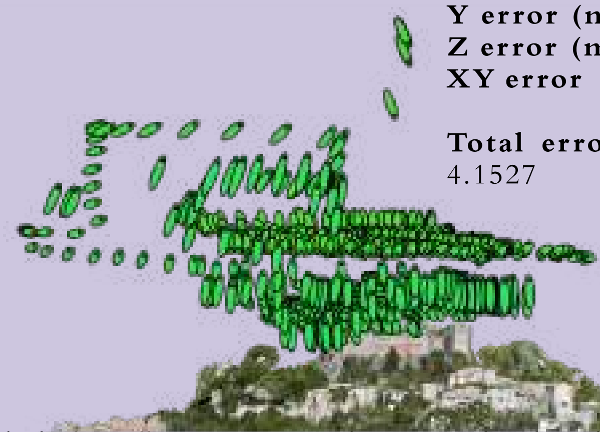
Resolution
4000 x 3000

Focal length
4.49 mm

Camera Locations

Camera locations and error estimates.



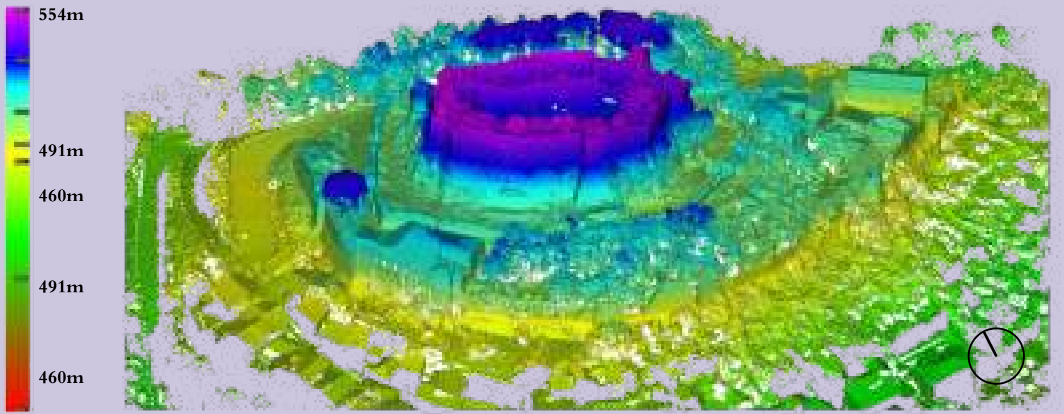


X error (m) 1.74732
Y error (m) 2.40255
Z error (m) 2.90164
XY error (m) 2.97075

Total error (m)
4.1527

Estimated camera locations are marked with a black dot. Ellipses represent the error related to the cameras positioning after the resolution of the SfM process. The total error is the probability of distribution of the cumulative error, which here is less than 4%. The survey is well performed.

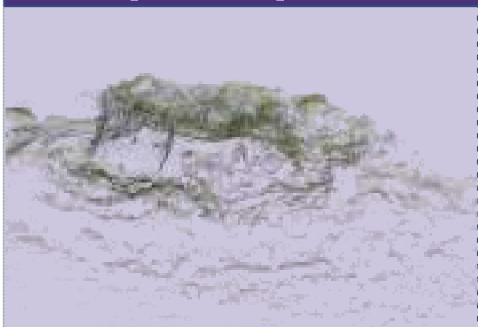
DEM_Digital Elevation Model



Stereo image pairs from an image collection are used to generate a point cloud representing the 3D locations for each of the connection points extracted from the images for which elevation data can be derived.

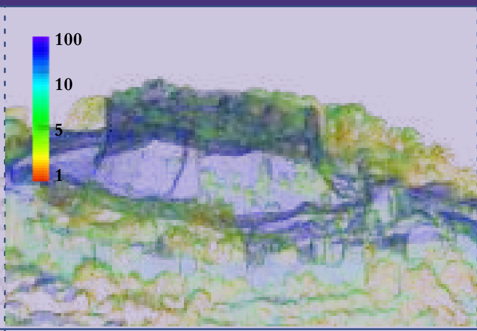
The derived elevation data can be visualized in a digital terrain model (DTM), which includes an estimate of the ground surface, and a digital surface model (DSM), which includes elevations of above-ground features.

Sparse cloud point



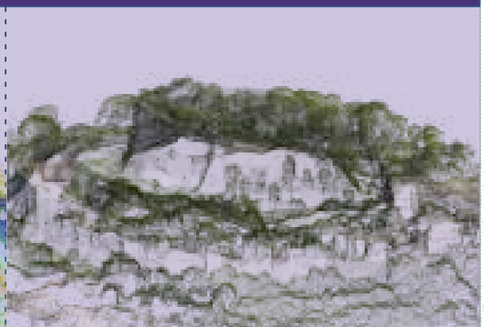
Key points resulting from the Structure from Motion process of camera alignment. First alignment step: the result is a sparse point cloud.

Confidence factor



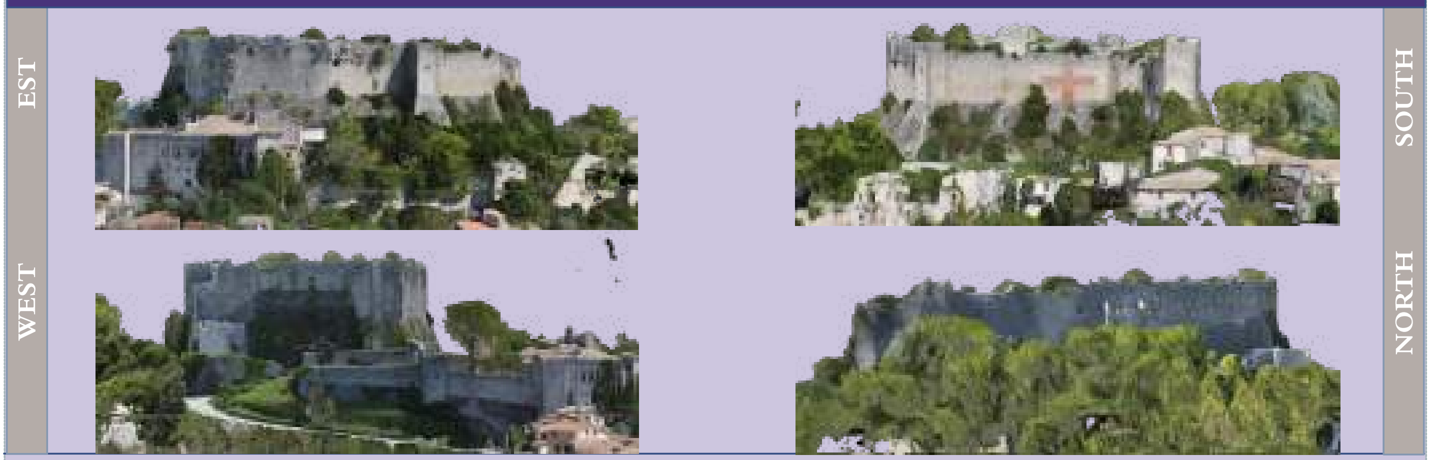
Representation of the confidence factor, which indicates from how many frames the photogrammetry software records information and how accurate it is. Blue indicates the most accurate value (100%)

Dense cloud



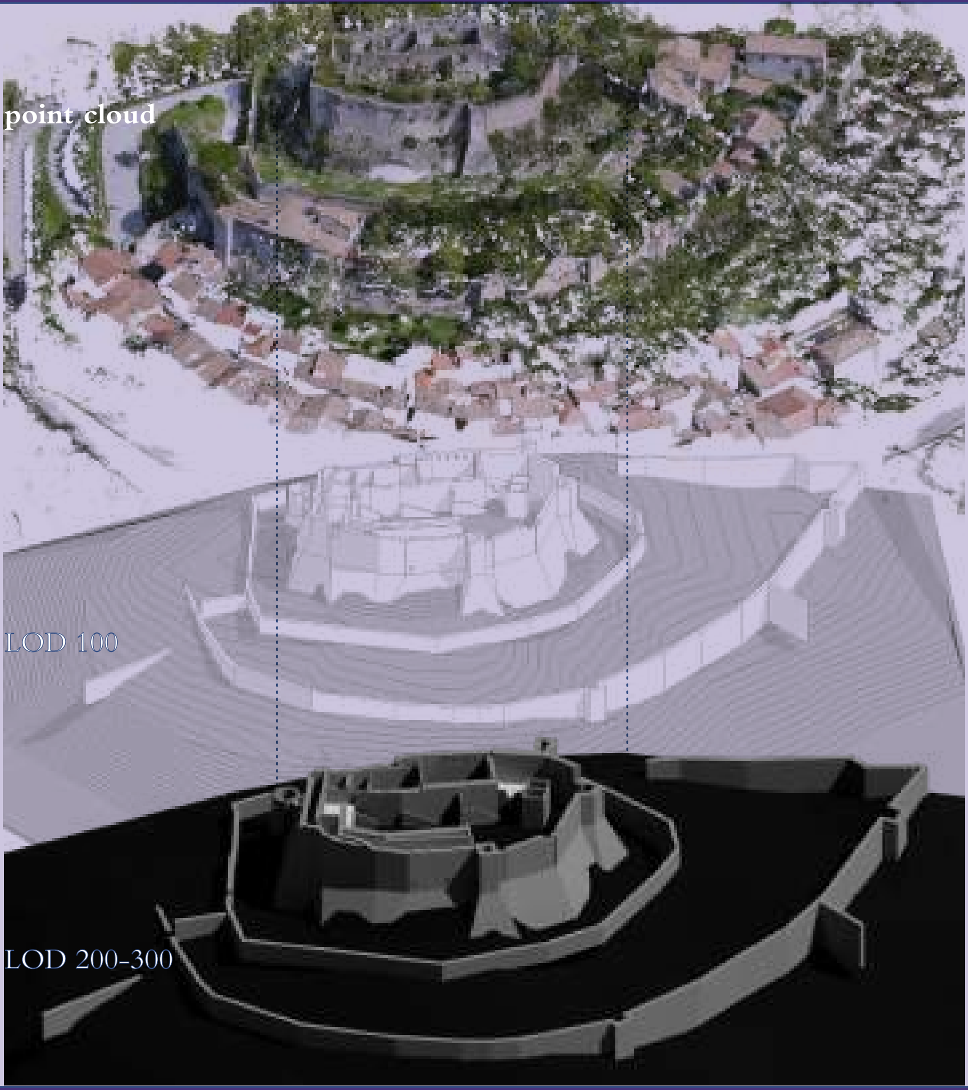
The dense cloud is characterized by a high density of points, providing a highly detailed and accurate spatial distribution of the features. It is the basis for creating 3D models and analyses.

Tiled model



The tile model is based on a dense point cloud and represents a high resolution, large-scale 3D model visualization. Its hierarchical tiles are derived from the original images, providing more information about the texture of the masonry.

SCAN TO BIM Procedure



INPUT

point cloud
.rcp file

point cloud
.rvt file

LINK

Vicalvi Castle.rvt file

Architectural model

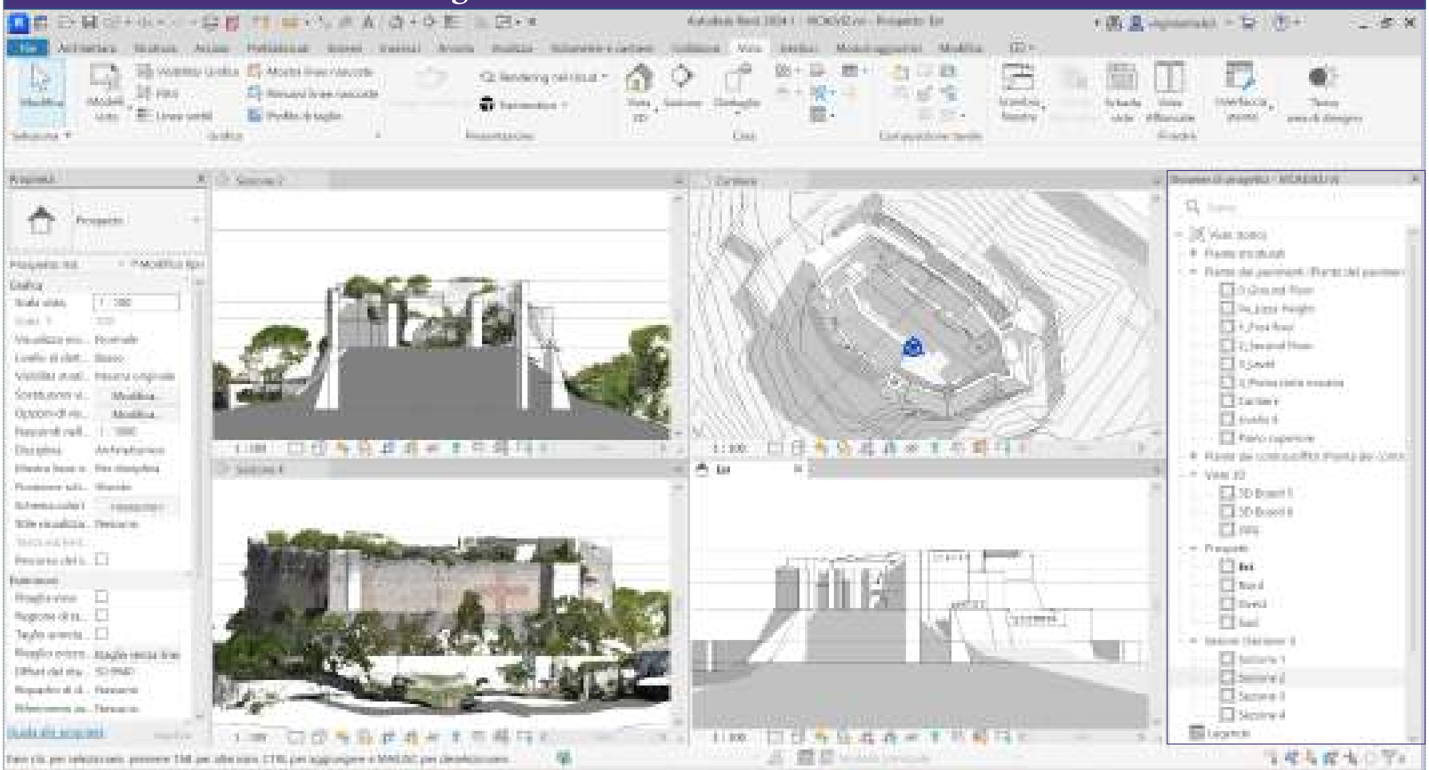
Features

(low) LOG &LOI	(high) LOG &LOI
Plugin in Revit	Revit families

OUTPUT

Structural Analysis	HBIM model

HBIM Parametric Modeling



_Definition of levels and design grids

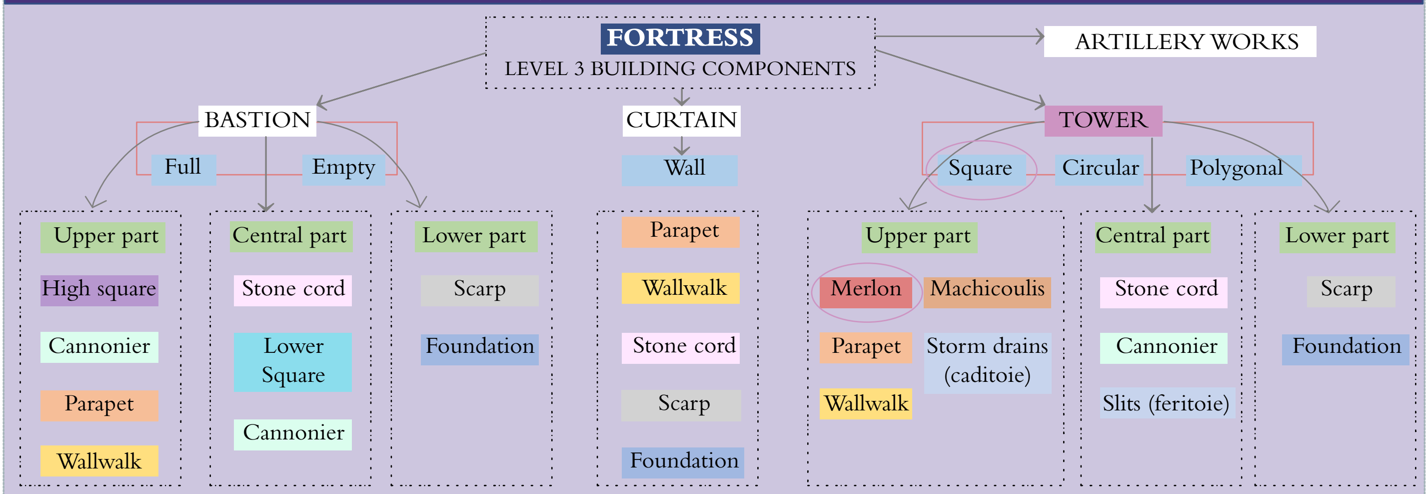
_Definition of design attributes (walls, floors, roofs)

_Modeling according to the point cloud: elaboration of the state of the art

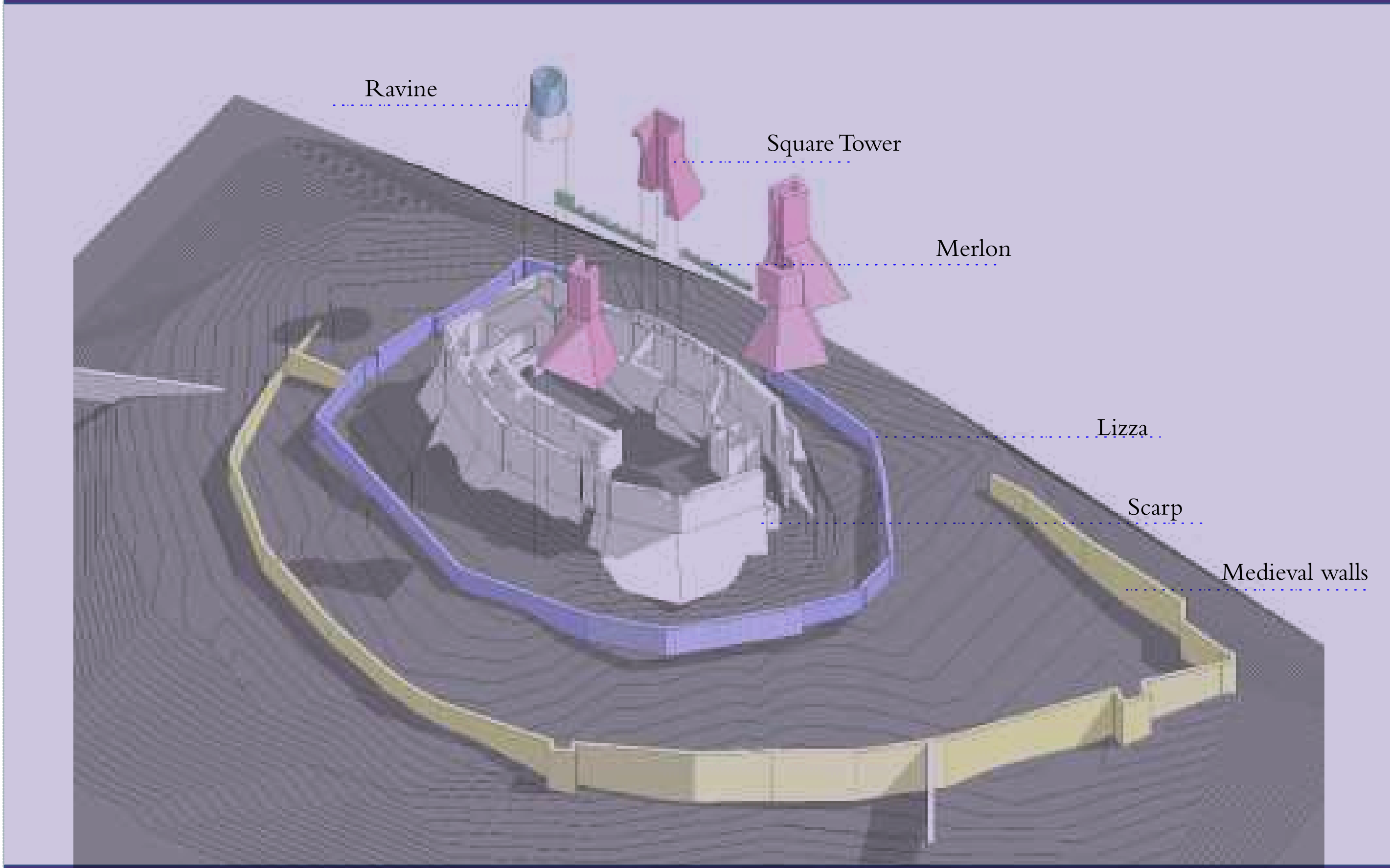
_Material and structural information of "wall, roof, floor" objects

_Modeling of local parametric families

Semantic segmentation and ontology construction (WBS)



Semantic enrichment of the HBIM model



Glossary extract – LOI

Ravine: Robust, additional, advanced fortified work, shaped as a V or rectangle or semicircle, placed before a gate. It had its own moat and was also used for flanking firing. It was often connected to the tong or curtain wall behind with a gallery. External work built outside the curtain wall of the main ones, shaped in a V or semicircle, to cover weak or exposed points (for example, the head of a bridge). Some, medieval ones especially, have square, rectangular or round shapes. It often has its own defensive moat, connected to the main one.

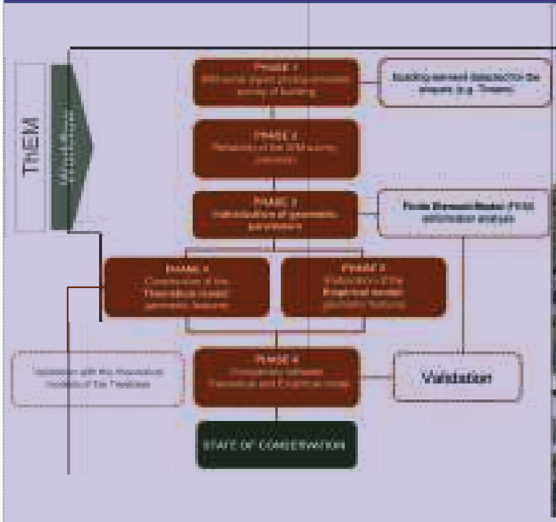
Lizza: land between two successive city walls (usually between the second and third). When it remained free of superstructures it was used for tournaments and competitions.

Tower, (tour, Fr.) any high build ing raised above another, consisting of several stories, usually of a round form, though sometimes square or polygonal: a fortress, a citadel.

> **Tower-bastions**: in fortification, are small towers made in the form of batstions with rooms or cellars underneath to place men and guns in them.

Scarp: moat wall along the city wall or wall addition sloping at the base of the walls, to strengthen them and nullify the dead angles in front, to prevent the approach of mobile towers and the danger of mines.

THEM WORKFLOW | PHASE 1: SfM survey - identification of the architectural elements



Survey A

Date	06.09.2022
Time	10.00-12.00
Points n.	6,421,009
Frame n.	1107
Frame size	3000x4000
Height of fly	30 m

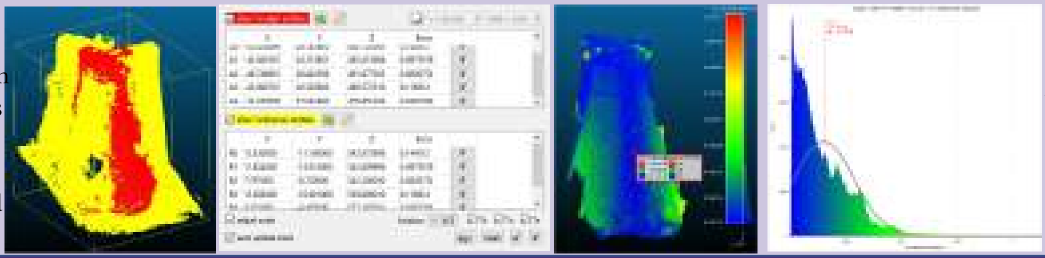
Survey B

Date	04.04.2023
Time	11.30-13.30
Points n.	7,342,659
Frame n.	1182
Frame size	3000x4000
Height of fly	30 m

PHASE 2: Reliability of SfM survey and Precision

Alignment

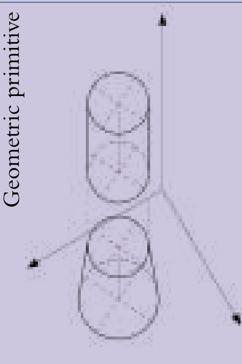
Process by which relative positions and orientations of multiple datasets acquired are determined.



Precision

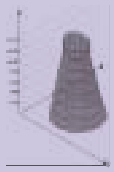
Difference between measured coordinates and actual coordinates in the global reference system.

Definition and construction of the models: Theoretical model and Empirical models



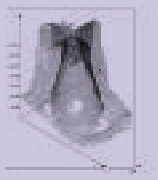
Vicalvi Ravine
Elliptical Cylinder
a' 5,80m
b' 5,82m
h' 6,61m
Truncated Elliptical Cone
a 7,63m
b 7,78m
h 5,04m

Geometric solid model



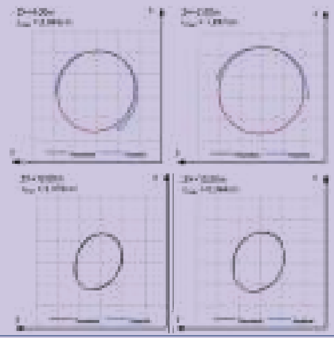
Theoretical model

Contour plot model
Photogrammetric model



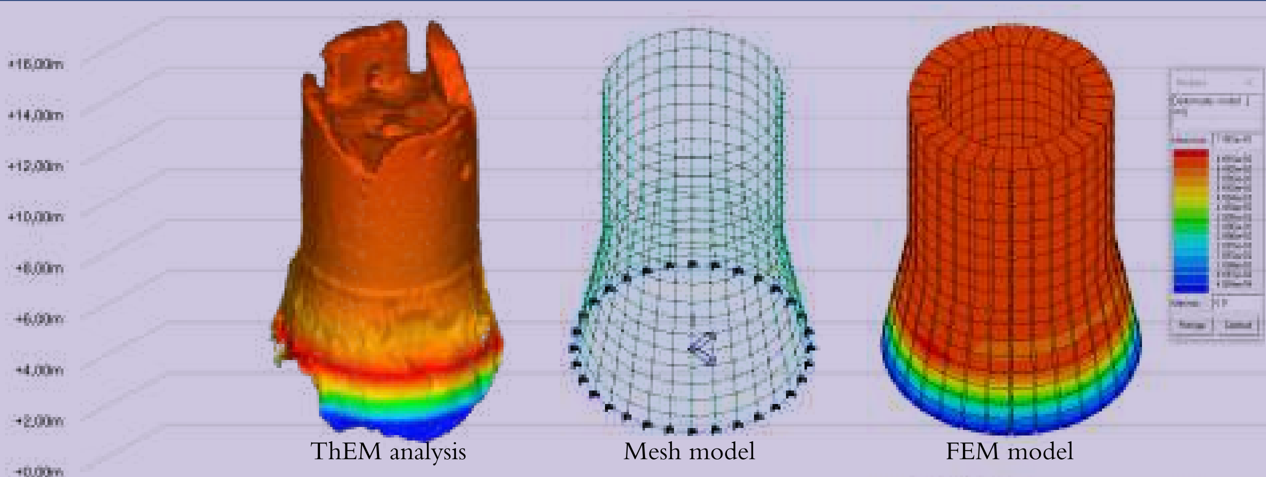
Empirical model

Comparison between the models and results



The tower's geometry is derived from the synthesis of solids, culminating in an idealized theoretical volume. An empirical model of the tower can be generated using mesh surfacing obtained from a digital point cloud. These two models enable the extraction of transversal and longitudinal sections. Examination of the tower's structure involves the extraction of cross sections at intervals mirroring the dimension of its stones. Discrepancies in distance and surface deformation between the theoretical and empirical models are scrutinized through a process of superimposition. Displacement data for each section are analyzed and segmented. The resultant output is depicted on a color-coded graphical representation, with regions of maximal deformation highlighted in red.

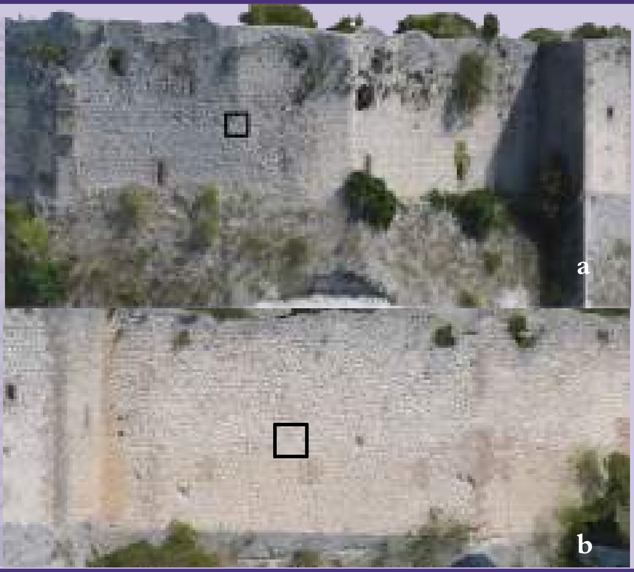
Validation of the procedure



ThEM analysis Mesh model FEM model

Reference: Pelliccio, A., Saccucci, M., & **Miele, V.** (2023). Deformations of the Fortress Towers Analyzed by the SfM Survey. Nexus Network Journal, 25(Suppl 1), 39-46.

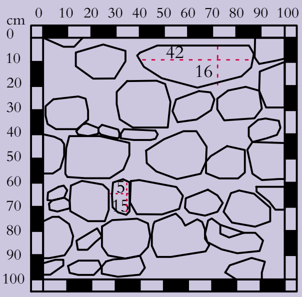
Samples identification for masonry analysis



Masonry consisting of natural resistant elements.

Masonry consists of stone elements bonded together by mortar. Stones obtained by felling rocks are laid in regular layers of uneven thickness, bonded by mortar.

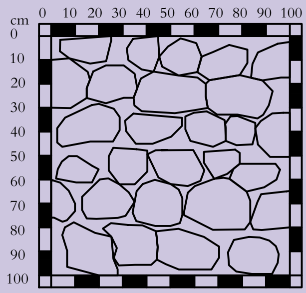
curtain wall (a)



	STONE	MORTAR
Area [m2]	0,8166	0,1834
Area [mm2]	816600	183400
%	81,7	18,3
Ratio Mortar/Stone	0,224	
Ratio solid-void:	0,22%	

The stone used is local calcarenite, in uncertain work with stone inserts of fair size but in good condition. the sample affects the first core of the castle.

curtain wall (b)



	STONE	MORTAR
Area [m2]	0,8184	0,1816
Area [mm2]	818400	181600
%	81,8	18,2
Ratio Mortar/Stone		0,222
Ratio solid-void:		0,22%

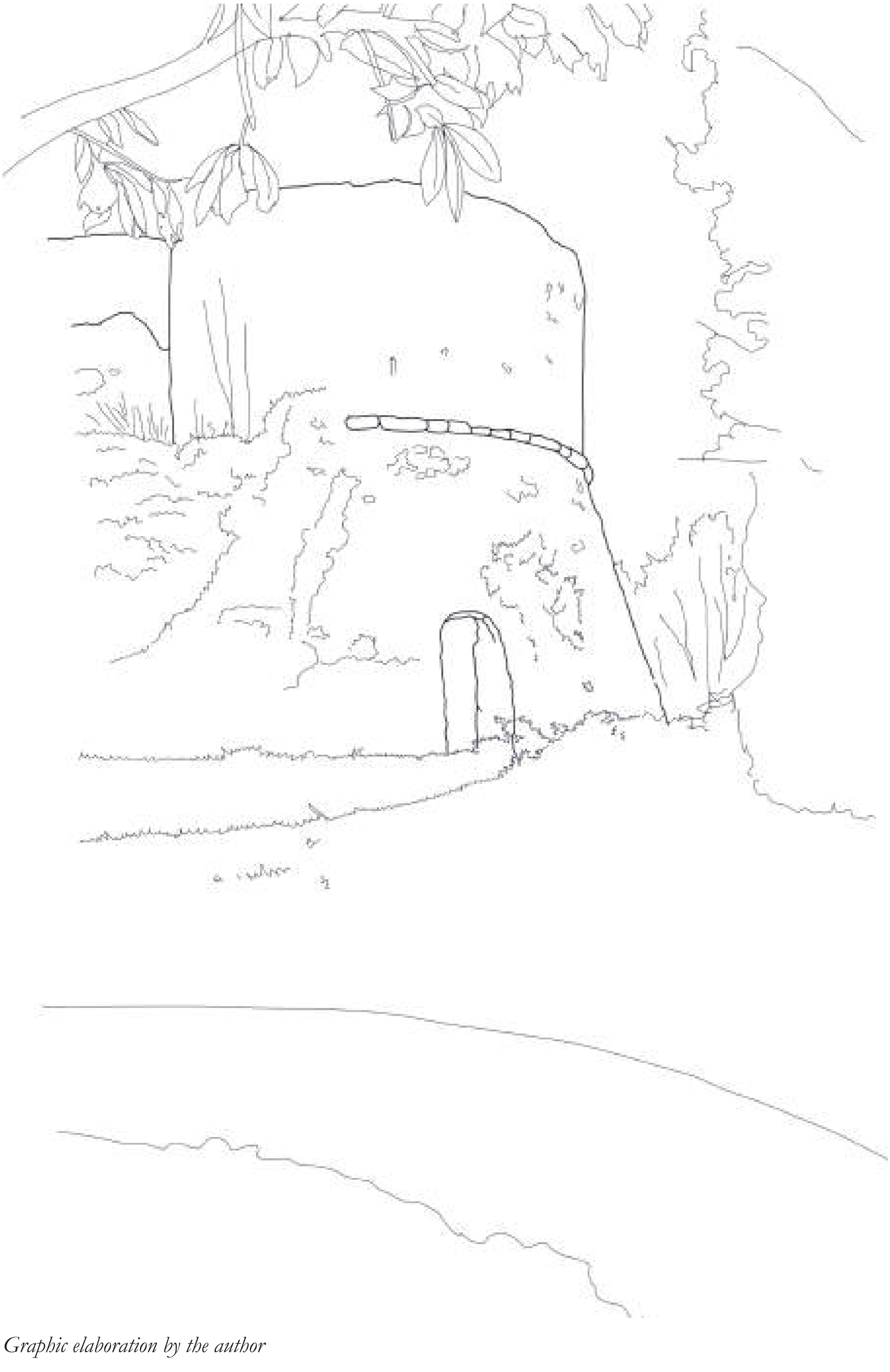
The stone used is local calcarenite, in uncertain work with stone inserts of fair size but in good condition. the sample affects the first core of the castle.

Synthesis Masonry features

	Material	Characteristics	Dimensions
Stone block	Lithology Sedimentary rock clastic (local calcarenite)	Superficial processing – roughing – squaring Color –Yellowish; – grey Shape – irregular	Block (hxb) min: 32x16 cm max: 57x26cm
	Mortar composition	Morphology and surface finish:	Thickness
Joint	aerial lime mortar (?)	-indented – degraded	Horizontal 3 – 30mm Vertical 3 – 10mm
Texture	Opera incerta		
Section	Nucleus undetected	Sack masonry	Total thickness 2m Nucleus: n.r
Description	Masonry with two faces occasionally connected with through elements (diatons) Made of local stone foundations, of small and large size, set to opera incerta with earth bedding and repointing		

Sample sheet of masonry technique. References to current standards for the parameters components of the sheet:

_NTC 2018 (Technical standards of construction)
_CIRCOLARE 21 gennaio 2019 , n. 7 C.S.LL.PP



Graphic elaboration by the author

View of Alvito castle, photo taken by drone by the author in collaboration with engineer Marco Saccucci.

DESCRITTIONE
DEL
DVCATO D'ALVITO
NEL REGNO DI NAPOLI,
IN CAMPAGNA FELICE
Divisa in due Parti.
DI GIO: PAOLO MATTHIA CASTRVCCI,
D'Alvito Dottor Filosofo, e Medico,

Fig.7 Frontispiece of Descrittione del Ducato d'Alvito, Giovanni Paolo Mattia Castrucci, 1633. (https://books.google.it/books/- last access 25.09.24)

3. Alvito Castle

The city of Alvito is laid out on many levels on one of the southern slopes of Mount Morrone, on a lesser peak known in ancient times as Monte de Albeto or Serra de Albeto. Its present urban structure is the result of a long process of settlement that began in the 11th century and significantly affected the large territory surrounding Sant'Urbano, an ancient administrative center founded by Abbot Aligerno of Montecassino in 976. Upon this area, which today goes by the name Colle della Civita, there once stood the Civita Sancti Urbani, probably destroyed by Saracen raiders in the late 9th century during their attacks on the Terra di San Benedetto. Following the incursions by the Arabs, Abbot Aligerno started the work of land re-claiming, including building a castle. This fitted within a greater territorial reclaiming strategy for the Terra di San Benedetto to regain lands lost during the so-called "exile of Teano."

Yet the new settlement did not last. Demographic growth, by the end of the 11th century, produced abandonment both of the castle and the village around it. The failure in its integration of urban life with the agricultural land outside its

walls favored the migration of people toward places where agricultural activity was concentrated.
Nevertheless, the reconstruction works strengthened Montecassino's presence in the region and guaranteed that it could support its monks, gaining economic autonomy and consolidating the northern borders of the Capua Principality and Diocese of Sora in Marsican territory.

3.1 Historical Documentary Survey

In the late 11th century, Sant'Urbano was in ruins, and from 1096, references to the territory describe it as Monte Albeto, after the Norman invasion. This surely indicates that the urban center had moved to new settlements on the slopes of Mount Morrone or, quite simply, that fortifications no longer existed. The administrative unity of Cassino broke down, and with it went any territorial arrangement and economic system based on the possessions of Montecassino. The reaction of the abbey was to give the territory to the d'Aquino family within the frame of a territorial restructurization of the Terra Sancti Benedicti. To this family, up until then hostile to the Benedictine prevailing, was given the task of administrating lands in Settefrati and Posta Fibreno in exchange for Piedimonte San Germano. The recipient, Adenolfo d'Aquino, was granted an urban center of over 120 settler families. This would establish the base for the Castle of Alvito, though the land was granted for only one generation. It was the consequence of the weak Sant'Urbano administrative structure and the continuous reorganization of territorial power that brought about the decline of the Civita Sancti Urbani administrative influence. This was a center in decline because of the loss of economic and urban vitality in the area since, in particular, Abbot Desiderio's fortification initiatives.
The "Incastellamento" of Monte Albeto

Unstable was the dominion exerted over Valcomino by the d'Aquino family due to the turbulent dynamics present between the Normans and the Papal State. Throughout this period, Alvito remained exposed to Norman raids, especially at the end of the 11th century. The most famous episode happened when Gionata, Count of Carinola, promoted a military campaign against the County of Sora, which also had some effects on Alvito. Disagreements between Rainulfo d'Aquino and the local people furnished an excuse for Norman interference, the result of which had been a siege that included Alvito.

These events marked the beginning of the decline of d'Aquino hegemony in the region. The capture of Rainulfo was bought with a hefty ransom of 200 pounds of gold by Abbot Oderisio of Montecassino. Contractual conditions imposed on Adenolfo's lands, stipulating that they could not be alienated due to ongoing improvements, suggest that efforts to construct a castle at Monte Albeto had commenced but remained incomplete.

The Fortification of Alvito

The fortification of Alvito is related to the Norman period, probably an endeavor shared by the Capua princes and the Abbey of Montecassino.

Built to safeguard the Kingdom of Sicily's strategic communication routes-in particular, between Abruzzo and Terra di Lavoro-these fortifications marked the transition from a patchwork of ecclesiastical and lordly properties to a more centralized system of castles under the Sicilian Crown. Alvito, or "castrum Albeti," appears in Ruggero II's Catalogus Baronum with a lord, Landolfo I d'Aquino, responsible for ten knights and thirty servants. By the late 12th century, the fortified center had evolved into a castrum—a term denoting a village protected by towers, walls, and a noble palace.

The Angevin and Aragonese phases

In the Angevin period, after the troubled wars to prevail over Southern Italy, the fortifications were developed further. The Cantelmo family gained the dominion of that area after the fall of the d'Aquino family's in the times of Manfredi and then the Angevin Conquest. Restaino Cantelmo married into the d'Aquino family and thus inherited the lands and castle of Alvito, promoting heavy rebuilding and strengthening of the fortress after the earthquake in the 14th century.

Under the rule of Cantelmo, Alvito reached its maximum development as a fortified center with the building of other defensive walls, towers, and a ducal palace. In the 15th century, the castle was still the most important administrative and military center. Later, in the early 16th century, it passed into the hands of the Spanish Navarro and Cardona families, after which it began to decline.

Up until the end of the 19th century, the castle had kept most of its structure intact; it was a series of earthquakes in the 20th century and subsequent neglect that brought many significant architectural features-keep and battlements-dooming it to ruins. The architectural complex has developed according to the principles of medieval military economics and has preserved the form of its structure without the common philological or mannerist restoration practices in other sites. The defensive system had several concentric walls, of which the outer perimeter surrounded the trapezoidal hilltop site. A second curtain wall enclosed the central buildings that had been protected by angled walls and four towers, each 14 meters high with a base circumference of 11 meters. The keep stood in the middle of the second wall, was 11 meters above the rest of the building, and nobles lived in the southern wing. Access was guarded by an octagonal tower with Guelph battlements. Since 1994, restoration has been attempted by the comune of Alvito, including rebuilding of the towers, battlements, and main entrances using original stone material. Despite this activity, much of the site remains under construction.

3.3 Georeferenced cataloging in GIS

GIS is one of the most important tools for documenting the fortifications in Southern Lazio from a spatial perspective. Georeferencing architectural remains and morphological data with historic maps helps to establish a coherent spatial framework through which holistic analysis may be conducted. The technology identifies the precise location of each fortification but also facilitates an understanding of strategic factors such as territorial dynamics, access routes, and lines of sight. This georeferenced database forms the basis for further research, thus allowing comparative studies to be made between the various fortified sites. The identification code for case studies within the GIS database is illustrated in Table 3, which defines the valley boundaries and draws special attention to the strategic locations of the castles. It also shows the zones of influence between the principal fortifications at Sora, Alvito, and Vicalvi, by analyzing the fortification intervisibility.

3.4 Geometric-Material Survey

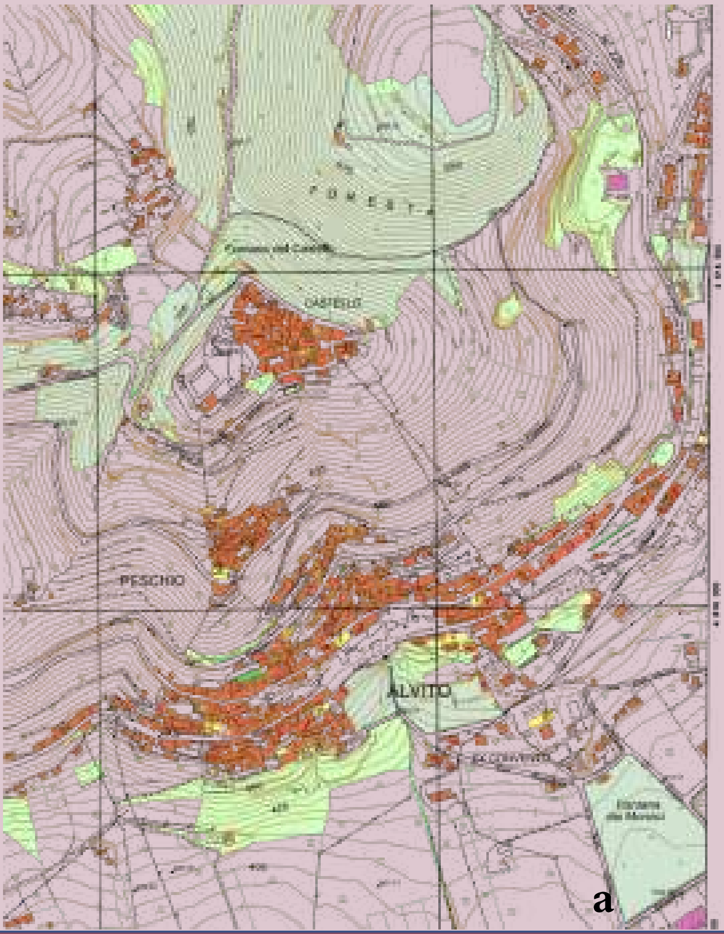
The geometric-material survey represents the first step in the documentation, and it aims to capture the accurate physical characteristics of fortifications. This includes recording dimensions, materials, and construction techniques. Traditional methods of measurement are complemented with drone-based photogrammetry, resulting in a high level of resolution for complete documentation of architectural features. In this regard, drone photogrammetry allows taking pictures of areas that are hardly accessible; this ensures totally documenting the site. The SfM methodology processes sets of images into three-dimensional digital reconstructions that preserve geometric accuracy, enabling detailed visual analysis. These digital models are considered essential for studying both current conditions and original structure related to the fortifications, and form the basis for restoration and conservation planning. Boards 4 and 4b present some of these results.

3.5 Ontological 3D Modelling using HBIM

The final phase involves the development of an ontological three-dimensional model based on HBIM methodology. In this step, data acquired through geometric-material surveys and photogrammetry are brought together and integrated into a functional digital model. Finally, HBIM integrates historical, material, and construction data into one framework that serves as a basis for architectural analysis and the simulation of different restoration scenarios. The model remains dynamic, changing and adapting with new data and further research integrated within the model. The results of this stage can be seen on boards 5 and 6.

3.6 Further Analysis

The base for deeper analysis is established through the implemented processes and the spatial and architectural databases that were created. Among them, the GIS database allows performing spatial analyses that are very important to enhance the understanding of territorial dynamics and inter-site relationships. Moreover, SfM techniques allow detailed dimensional analyses as shown in Chapter 4, Paragraph 7. These techniques proved effective not only for accurate volumetric modeling but also to provide effective structural insights, as shown in Tables 7 and 7b. SfM therefore appears as a diagnostic tool contributing to the discussion of construction techniques and stability of the investigated structures.



Typology	
Typo	Castle
Name	Alvito castle
Property	Public owner - municipality
Localization	
Municipality	Alvito, (FR)
Elevation	700 mt ca asl
Coordinates	41°41'31.34"N - 13°44'24.87"E
Consistency	
Surface	ca m^2
Volume	ca m^3
Masonry	Opera incerta - local calacarenite; non-squared stone masonry
Scarp	Yes
Conservation Values	
State of conservation	Medium/ Partly restored
Integrity	Medium
Authenticity	Medium
Historical Significance	High relevance

Cartographic references:
a| CTR Comune di Alvito, Foglio 391091, Scala 1:5000, anno 2020, Geoportale Regione Lazio;
b|Drone sequence of architectural emergency (property of the author)

a

b


c


d

0 — The origins of Alvito Castle trace back during the period of Norman expansion in southern Italy. It was strategically positioned in the rugged terrain of the Comino Valley.

X - XI sec

Alvito Castle became significant during the Norman and Angevin periods. It played a role in the feudal system of the Kingdom of Sicily, serving as a residence for feudal lords and as a military outpost

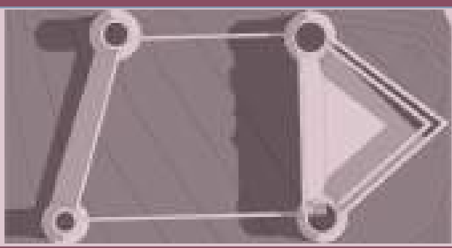
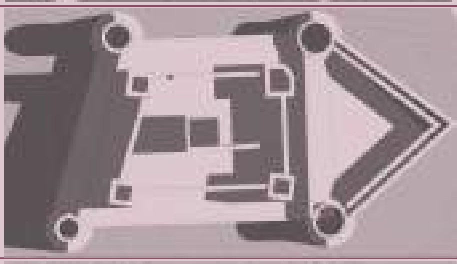
XII - XIII

1349 — Suffered severe damage in 1349, following a violent earthquake that exterminated the entire d'Aquino family

Renaissance period, Alvito Castle underwent renovations and expansions, incorporating elements of Renaissance architecture into its medieval structure. It continued to serve strategic and defensive purposes under the Angevins and the Aragonese

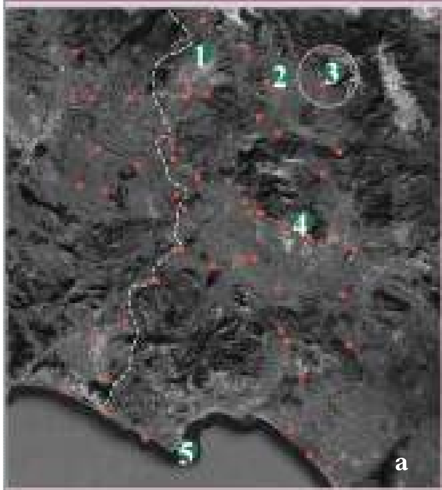
XV sec

XX sec — Several 20th-century earthquakes and years of neglect, however, caused the collapse and loss of the most conspicuous architectural elements, from the keep to the battlements.

	DIGITAL GEOMETRIC MODEL	
XI Century		An early fortified nucleus was most likely built by the Counts of the Marsi, a household of Lombard lineage, at the end of the 11th century; it must have been a village protected by towers, walls and a fortress. The castle was constructed with the joint hands of the princes of Capua and the abbey of Montecassino.
XIII Century		A second circle of walls protected the building proper, protected by four scarp walls, with four corner towers 14 meters high and 11 meters wide in circumference at the base and 9 at the top. In the centre of the second circle stood a quadrangular building, the keep, which rose 11 meters higher than the rest of the castle
XV Century		During the Renaissance period, the castle is greatly enlarged, and a cistern and chapel are inserted inside. The rooms on the south side of the building were to be the nobility's, while the remaining rooms housed the servants and guards. An octagonal tower protected its access. Guelph battlements" (Rogacien P., The Castle of Alvito, in "Spazio Aperto," 1993, no. 2)

References:
a | High relief in stucco, Alvito perspective, with the fortress, XVII century, Villa Gallio, Posta Fibreno; **b |** High relief in stucco, Alvito Castle facing east, XVII century, Villa Gallio, Posta Fibreno; **c |** Engraving on paper, (18700 ca); **d |** Historical photo, 1900.

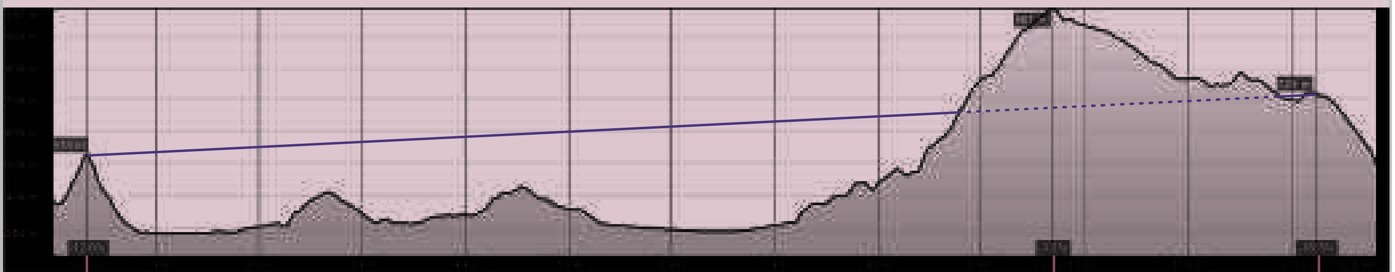
GIS fortresses database | Influence rays between Sora and Vicalvi - Fortifications intervisibility



Maps are georeferenced in WGS84 UTM32N (EPSG 4326)
a | Case study identification with ID code, Alvito Castle is represented by "03"
b | GIS analysis applied to fortifications in Latium makes it possible to understand the interaction dynamics between fortified structures and the surrounding territory. This integrated approach is crucial for understanding historical geography and territorial organisation. Intervisibility constituted the system's functionality, and today, the premise for ad hoc routes.

GIS | Fortifications intervisibility - Elevation profiles

SORA - ALVITO



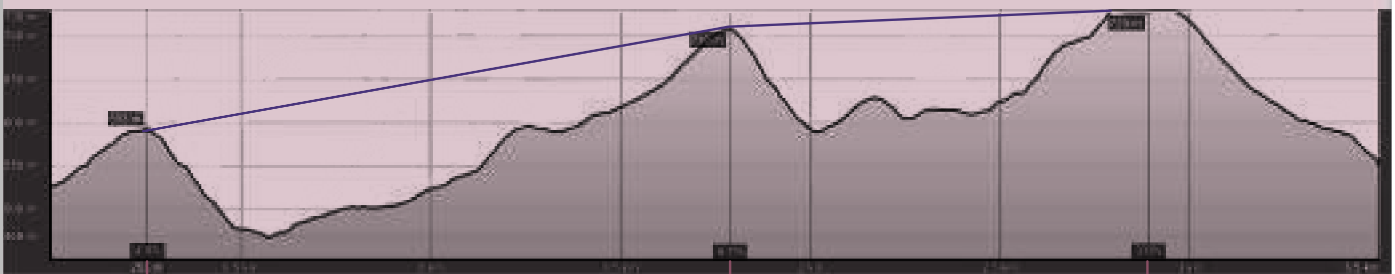
Sora
San Casto castle
530 mt ca

Mount
987 mt ca

Alvito
Cantelmo castle
720 mt ca

The elevation profile shows the impossibility for the San Casto castle to directly control the castle of Alvito. Therefore, communication with the castle of Vicalvi closely connected to both is essential.

VICALVI - ALVITO



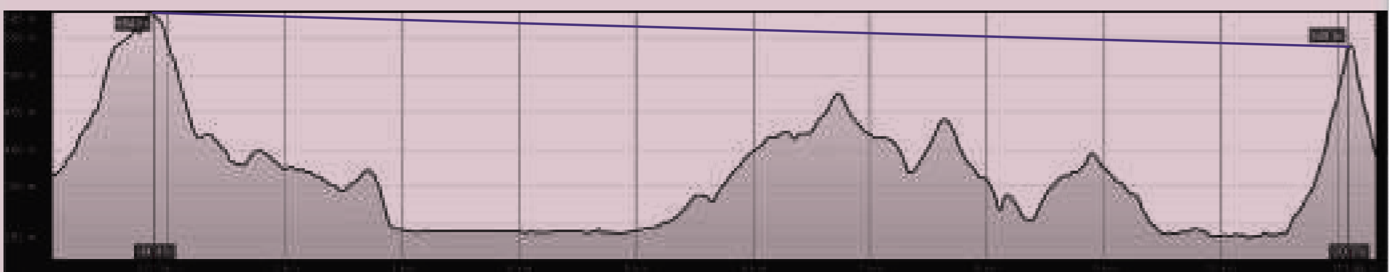
Vicalvi castle
590 mt ca

Monte Morrone
710 mt ca

Alvito castle
729 mt ca

The height of Mount Morrone between the two castles does not prevent communication due to the favorable orographic configuration

VICALVI - SORA



Vicalvi castle
590 mt ca

Sora
San Casto castle
530 mt ca

Flight plan

Report

Drone DJI Mini 2

Path n.1

Path n.2

Date 20.11.2021
Time 15:00-18:00

Number of images:	301
Flying altitude:	32 m
Ground resolution:	7.51 mm/pix

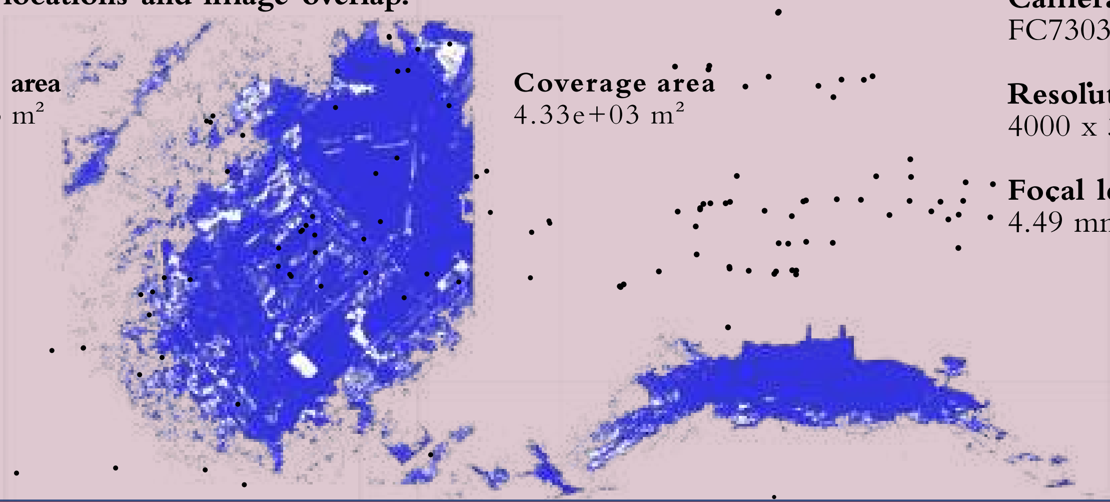
Camera stations:	298
Tie points:	307,736
Projections:	1,156,347
Reprojection error:	0.703 pix

Survey Data

Camera locations and image overlap.

Coverage area
1.55e+03 m^2

Coverage area
4.33e+03 m^2



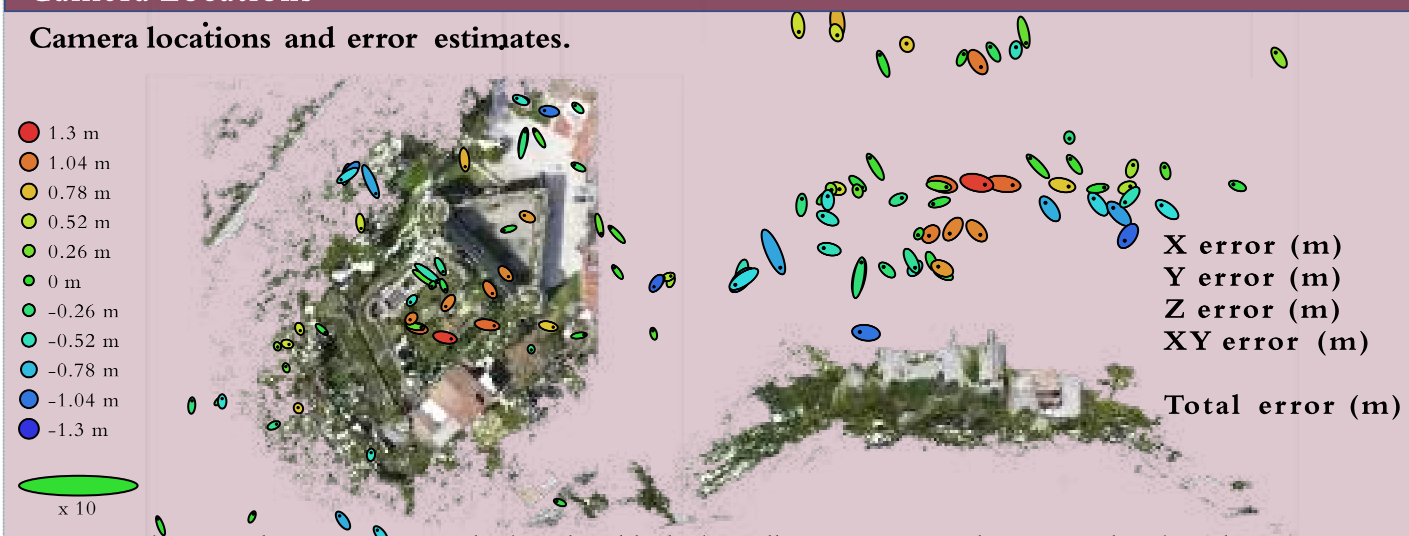
Camera Model
FC7303 (4.49 mm)

Resolution
4000 x 3000

Focal length
4.49 mm

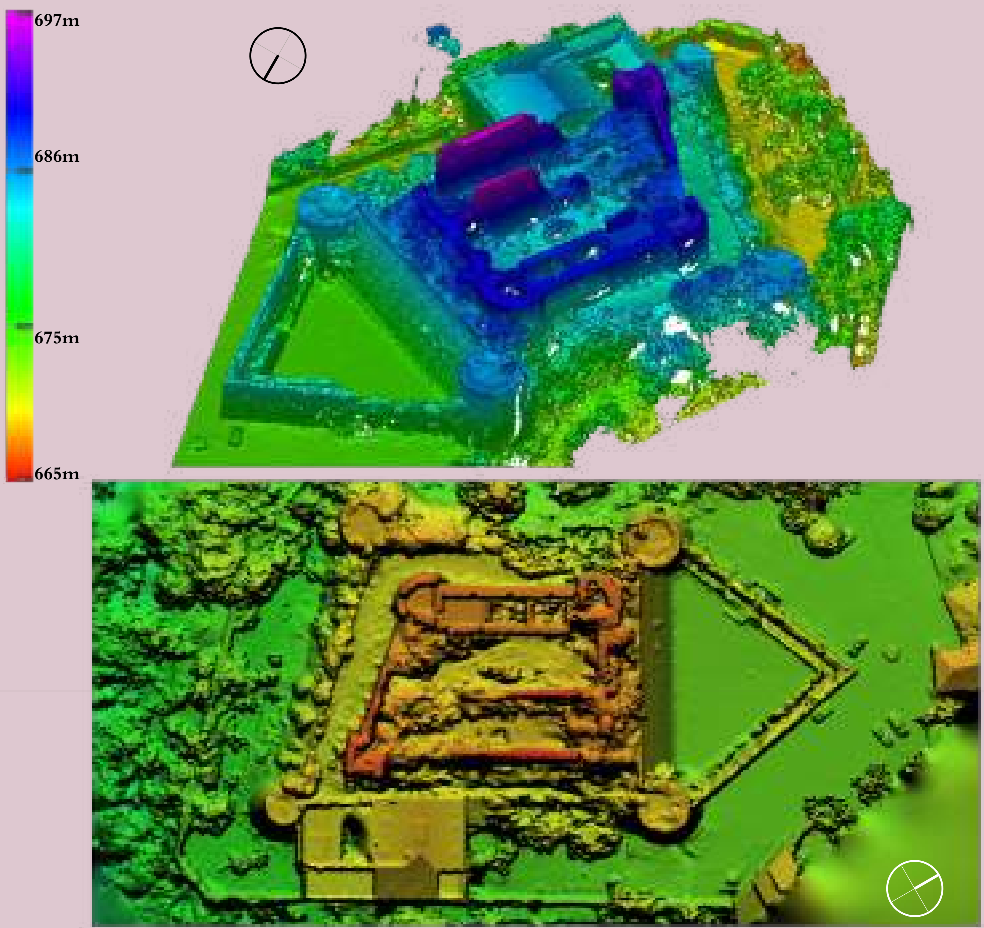
Camera Locations

Camera locations and error estimates.



Estimated camera locations are marked with a black dot. Ellipses represent the error related to the cameras positioning after the resolution of the SfM process. The total error is the probability of distribution of the cumulative error, which here is less than %. The survey is well performed.

DEM_Digital Elevation Model



Stereo image pairs from an image collection are used to generate a point cloud representing the 3D locations for each of the connection points extracted from the images for which elevation data can be derived.

The derived elevation data can be visualized in a digital terrain model (DTM), which includes an estimate of the ground surface, and a digital surface model (DSM), which includes elevations of above-ground features.

Sparse cloud point

Key points resulting from the Structure from Motion process of camera alignment. First alignment step: the result is a sparse point cloud.

Confidence factor

Representation of the confidence factor, which indicates from how many frames the photogrammetry software records information and how accurate it is. Blue indicates the most accurate value (100%)

Dense cloud

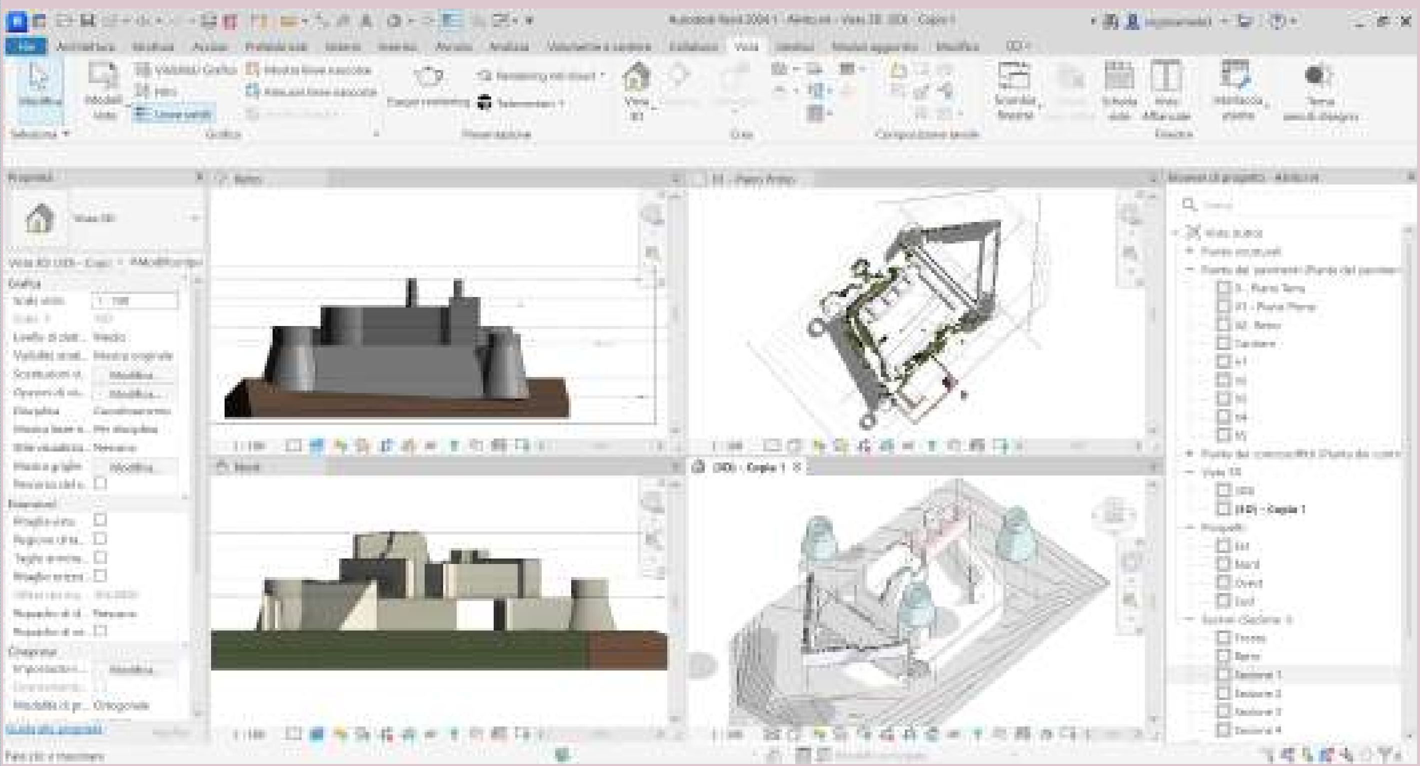
The dense cloud is characterized by a high density of points, providing a highly detailed and accurate spatial distribution of the features. It is the basis for creating 3D models and analyses.

Tiled model

The tile model is based on a dense point cloud and represents a high resolution, large-scale 3D model visualization. Its hierarchical tiles are derived from the original images, providing more information about the texture of the masonry.

SCAN TO BIM Procedure

HBIM Parametric Modeling



_Definition of levels and design grids

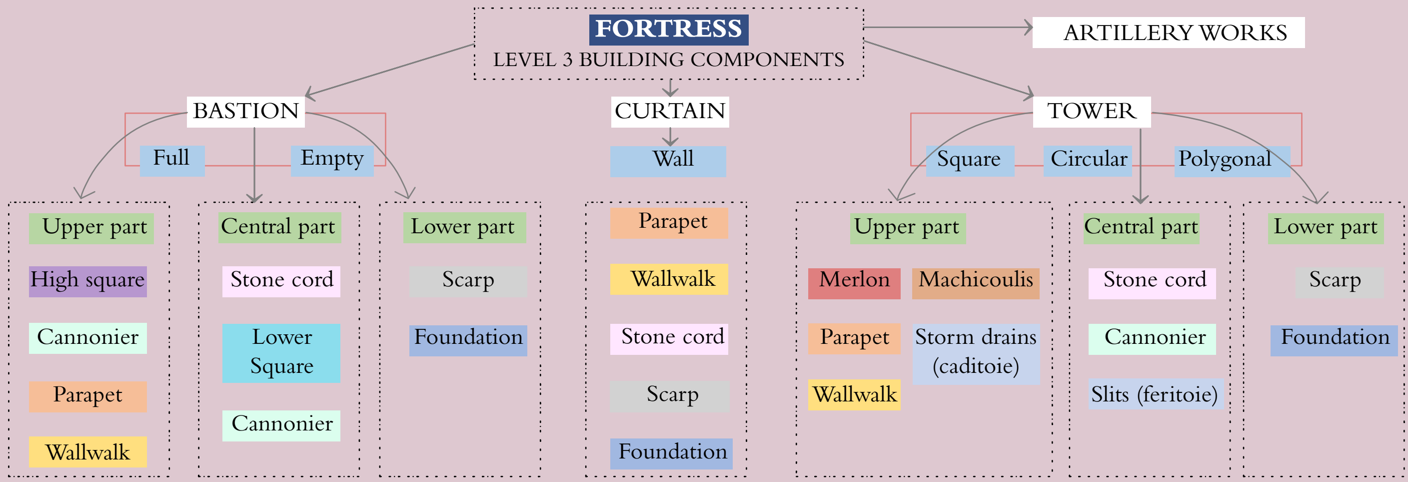
_Definition of design attributes (walls, floors, roofs)

_Modeling according to the point cloud: elaboration of the state of the art

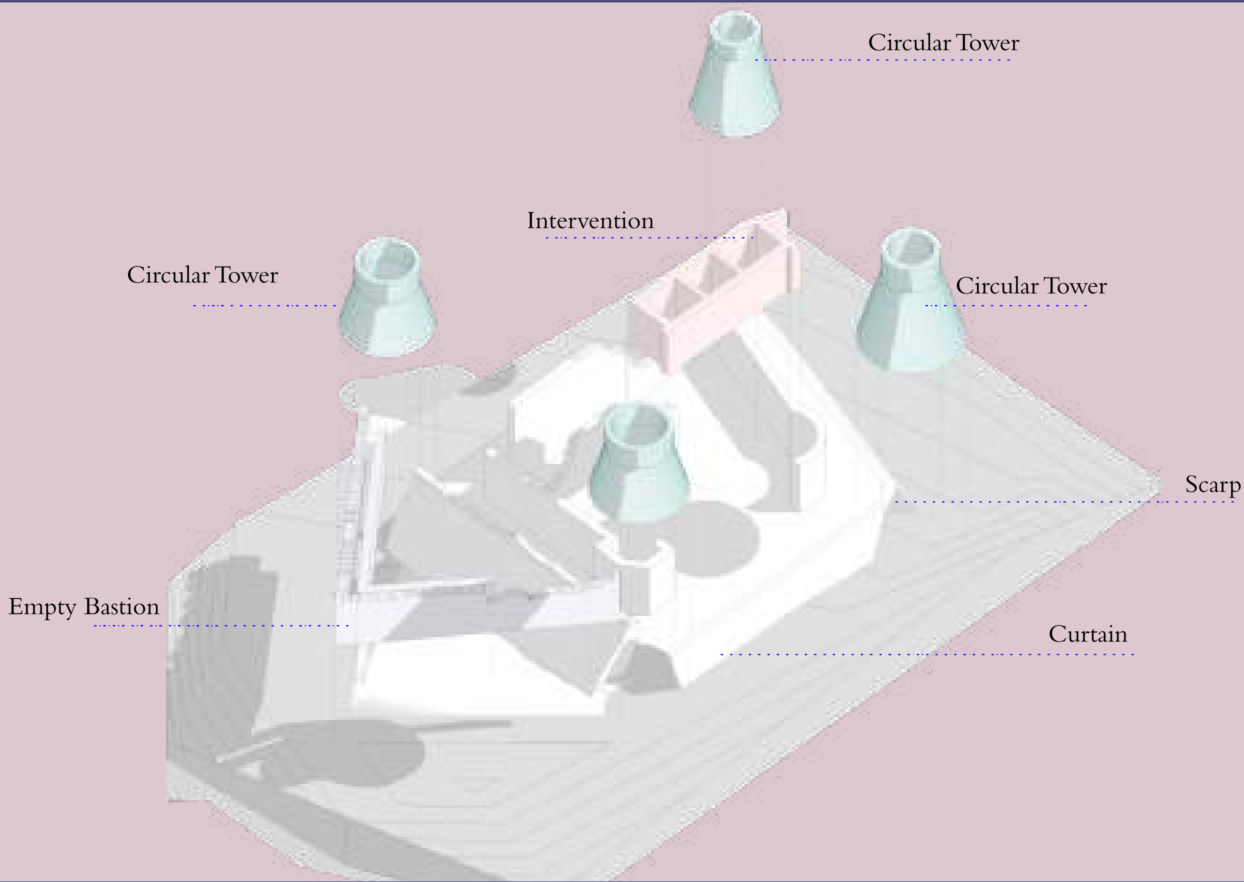
_Material and structural information of "wall, roof, floor" objects

_Modeling of local parametric families

Semantic segmentation and ontology construction (WBS)



Semantic enrichment of the HBIM model



Glossary extract - LOI

Arquebusier: slit cut in the walls to target attackers without exposing oneself, firing with blunderbusses. Depending on its specific use it was called: archer, crossbow and arquebusier, composite slits allowed the use of two or three different weapons.

Curb (or Stone cord): architectural expedient adopted on the outside of parapets or battlements to prevent slipping or ricocheting of projectiles launched from below.

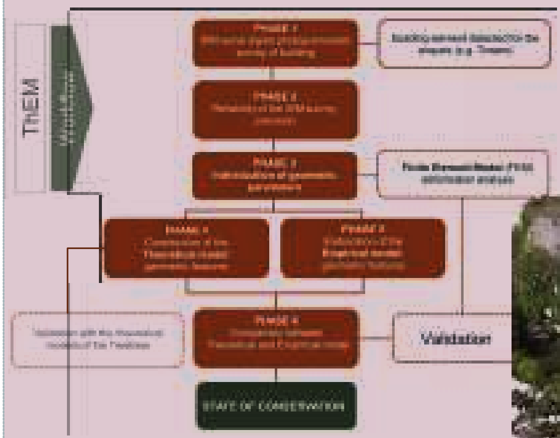
Cortina: Part of the wall between two successive towers or bastions. Essential element of any fortification, as it establishes the perimeter that must be defended.

Tower, (tour, Fr.) any high build ing raised above another, consisting of several stories, usually of a round form, though sometimes square or polygonal: a fortress, a citadel.

Tower-bastions: in fortification, are small towers made in the form of batstions with rooms or cellars underneath to place men and guns in them.

Scarp: moat wall along the city wall or wall addition sloping at the base of the walls, to strengthen them and nullify the dead angles in front, to prevent the approach of mobile towers and the danger of mines.

SfM survey and identification of the architectural elements



Survey A

Date	06.09.2022
Time	13.00-15.00
Points n.	6,422,118
Frame n.	986
Frame size	3000x4000
Height of fly	45 m

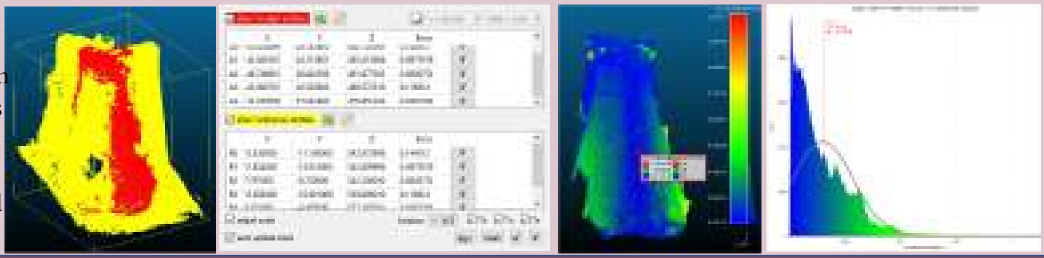
Survey B

Date	04.04.2023
Time	09.00-11.00
Points n.	5,100,019
Frame n.	1107
Frame size	3000x4000
Height of fly	45 m

Reliability of SfM survey and Precision

Alignment

Process by which relative positions and orientations of multiple datasets acquired are determined.

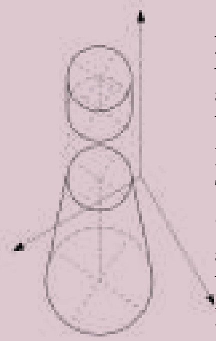


Precision

Difference between measured coordinates and actual coordinates in the global reference system.

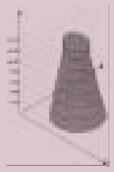
Definition and construction of the models: Theoretical model and Empirical models

Geometric primitive



Alvito Tower
Elliptical Cylinder
a' 6,54m
b' 6,46m
h' 3,02m
Truncated Elliptical Cone
a 10,82m
b 11,03m
h 10,32m

Geometric solid model

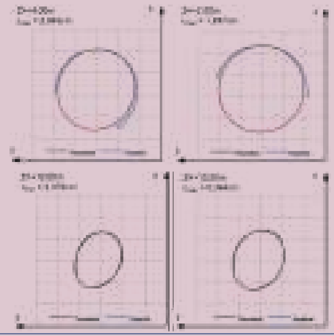


Theoretical model

Contour plot model
Photogrammetric model

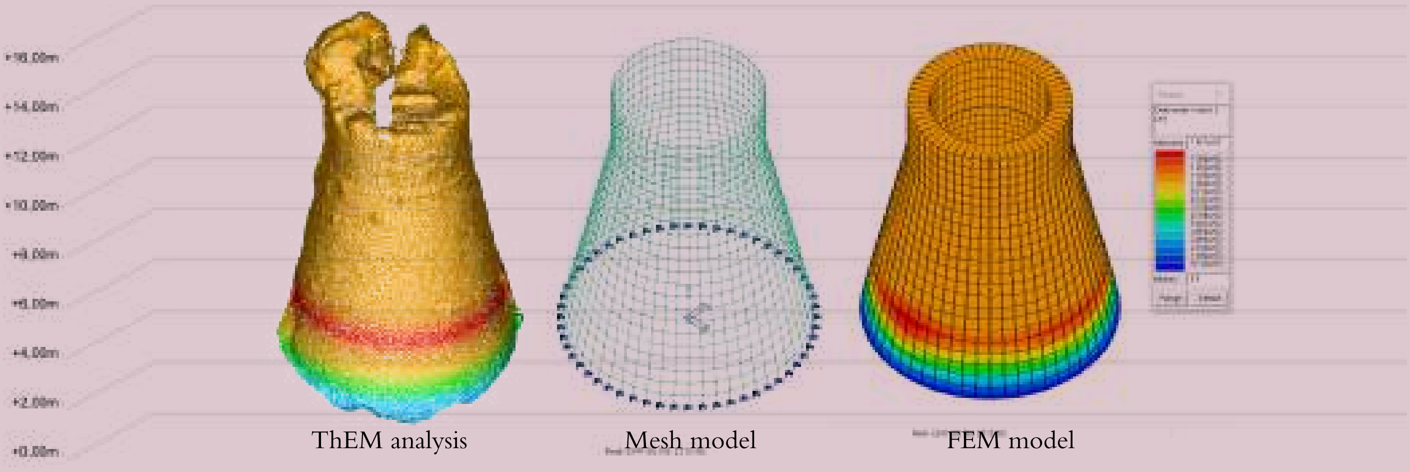
Empirical model

Comparison between the models and results



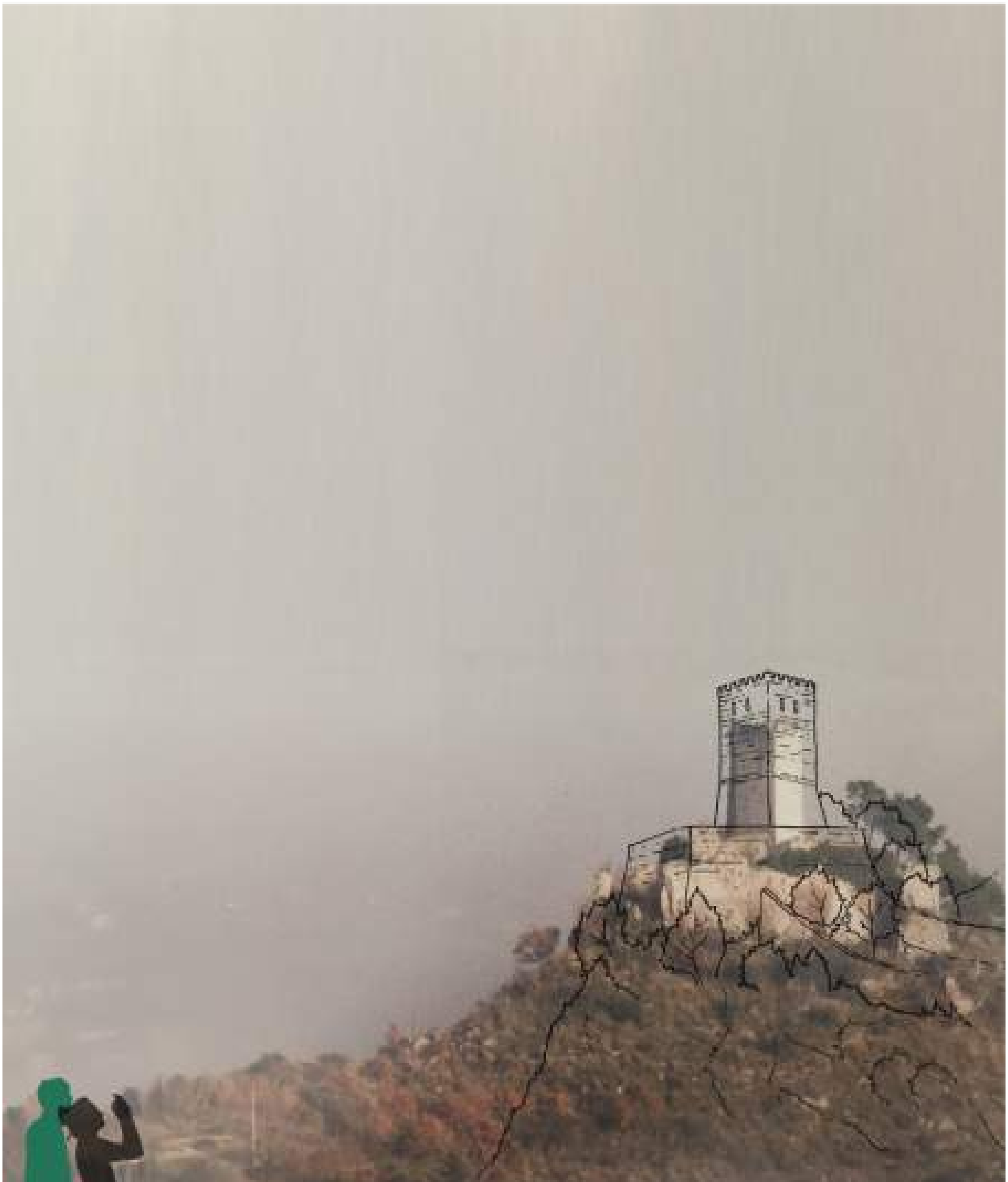
The tower's geometry is derived from the synthesis of solids, culminating in an idealized theoretical volume. An empirical model of the tower can be generated using mesh surfacing obtained from a digital point cloud. These two models enable the extraction of transversal and longitudinal sections. Examination of the tower's structure involves the extraction of cross sections at intervals mirroring the dimension of its stones. Discrepancies in distance and surface deformation between the theoretical and empirical models are scrutinized through a process of superimposition. Displacement data for each section are analyzed and segmented. The resultant output is depicted on a color-coded graphical representation, with regions of maximal deformation highlighted in red.

Validation of the procedure



ThEM analysis | Mesh model | FEM model

Reference: Pelliccio, A., Saccucci, M., & **Miele, V.** (2023). Deformations of the Fortress Towers Analyzed by the SfM Survey. Nexus Network Journal, 25(Suppl 1), 39-46.



"La torre pentagona, che sorge sulla cima più alta, sopra un ripiano cinto da forti mura, che la proteggono dagli attacchi del nemico in tutti i lati, nella sua irregolarità, presenta uno spigolo resistente agli attacchi del nemico che più facilmente poteva venire dalla campagna pianeggiante."

Graphic elaboration by the author

View of Rocca Janula, photo taken by drone by the author in collaboration with engineer Marco Saccucci.

Fig.8 Engraving of Monte Cassino and San Germano (Mabillon), 1739

4. Rocca Janula, Cassino

The Janula fortress in Cassino constitutes one of the most significant monuments for the local community and Terra Sancti Benedicti. It represents a heritage of solid historical, symbolic and identity value. Unfortunately, the damage suffered during World War II and more recent restoration works hinder the interpretation of the "real phenomenon" and the perception of the genius loci. In fact, the fortress has undergone massive intervention aimed at filling the architectural gaps, which are now not easily recognizable.

4.1 Historical-documentary survey

Rocca Janula, which occupies an offshoot of Monte Cassino, was founded in the period between 949 and 967. It was built as a defensive structure of the famous Benedictine abbey located a little higher up.

"[...] The picturesque line of this dark, crenellated castle contrasts with the tranquil form of the majestic building overlooking Mount Cassino, and its ruined parts suggest the sacrifice that this modest castle had to undergo, for the sake of the Monastery [...]" (Paterna Baldizzi L., 1913)

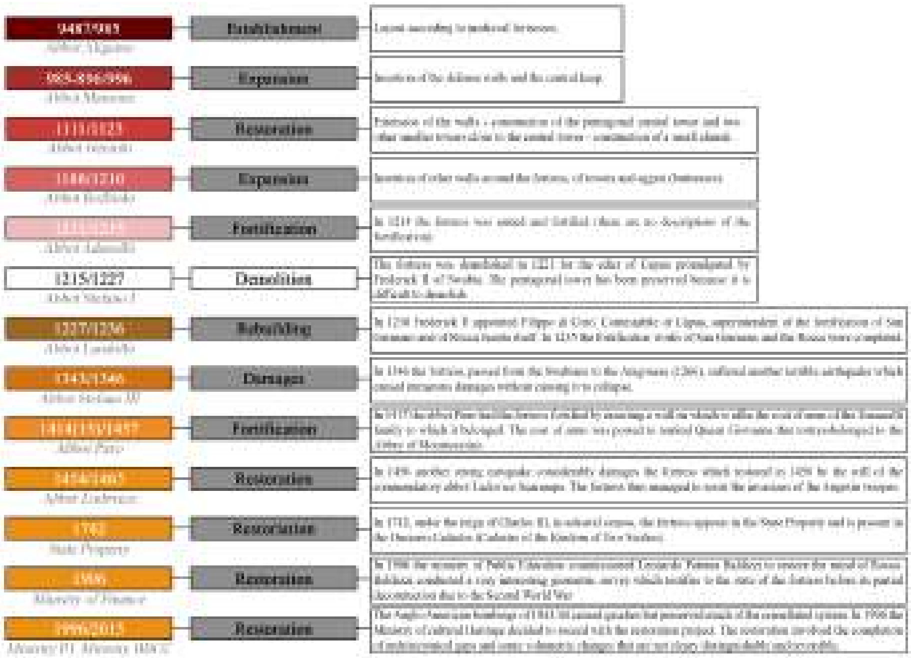


Fig.9 Synoptic diagram of the main evolutionary phases of Rocca Janula from its origins to the present day. author's elaboration

The fortress's events are in fact closely linked to those of the Abbey. The numerous transformations, destructions and restorations were due to the will of the Abbots, in addition to natural events, such as strong earthquakes, which often involved southern Latium. Hypotheses about the origin of the place name "Rocca Janula" are diverse. The Chronica Sacri Monasterii Casinsensi [Della Noce A., 1668], identifies "Janulo" with the name of the pagan deity of Janus Bifrontes to whom a temple was dedicated in the area where the fortress arose [Della Noce A., 1668]. A second hypothesis derives the place name from the Latin word iŌnŭa (small door) due to the presence of a small passage in the walls of the fortress that led to the Montecassino Abbey. The third and most articulate is based on the presence of the same toponym in the area around the city of Rieti. Indeed, the "castellum quod nominatur Ianule" appears in the list of castra acquired by Abbot Berardo I (1047-1089) of the Benedictine Abbey of Farfa. Rocca Janula was thus part of a group of seven castra offered by the last counts of Rieti to the abbey of Farfa [Toubert P., 1973]). From the early Middle Ages to World War II, the fortress was an undisputed protagonist of the history of the Italian territory: Carolingian, Saracen, Norman (with Frederick I the Redbeard and Roger II), Swabian (Frederick II), Angevin (Charles of Anjou), Aragonese (Alfonso of

Aragon) and Bourbon (Charles III). Very few studies have been conducted on the fortress, however, but the numerous documentary and iconographic sources make it possible to trace its main historical phases. A careful historical examination, gathering numerous sources, was conducted by Leonardo Paterna Baldizzi for the restoration of the fortress, carried out between 1907 and 1910 [Toubert P., 1973]. All the historical data collected by Paterna Baldizzi, with the support of the Benedictine father D. Luigi Tosti, and his thorough reconnaissance were published in the Memoirs of the R. Accademia di Archeologia, Lettere e Belle Arti (Vol. II, 1911) under the title "Rocca Janula in art and history." The study points out that the history of the fortress can be divided into three main phases. The first phase covers the period from its foundation to its demolition in 1221, following the Edict of Capua, promulgated by Frederick II of Swabia, which provided for the demolition of all castles and fortresses in his kingdom. The pentagonal tower was the only element that survived demolition because of its construction characteristics. The second phase encompasses the time from the reconstruction around 1235, which took place under Abbot Landolfo at the behest of Frederick II himself, to World War II, which caused considerable damage mainly due to bombing by allied troops. The third and final phase runs from the postwar period to the present, and is characterized by a partial restoration of the fortress (Fig.2). The intervention, by the Ministry of Culture, began on November 20, 1996, and was completed on September 25, 2015. The intervention concerned the numerous structural deficiencies, just on the western part of the fortress, and the arrangement of the external area of the perimeter walls, with "the redevelopment of the embankment in front of the main entrance and arranged in the time of Frederick II to allow the use of wagons" (Pistilli E., 2000). The summary of the main events that have characterized the most significant transformations of the fortress, from its origins to the present day, is contained in Fig.9.

4.2 Evolutionary hypothesis of Rocca Janula

Of the earliest historical phase of the fortress, which as mentioned goes from its origins to 1221, there is only a written narrative. The model, in this case, is the synthetic reproduction of the narrated object. The narrative is taken from Leonardo Paterna Baldizzi's study, according to which the fortress, located in an area with a strong overhang to the north due to a topographic ravine, has an original core with a quadrangular plan (about 3400sqm), defined by two sides of about 42mt and 66mt. The core follows the line of urban development of the underlying city of Cassino. It originates with an architectural structure similar to early medieval fortification structures (Coulson C., 2004). It can therefore be assumed that the layout was geometrically regular, characterized by circular towers, leaning against the corners, according to the description of Paterna Baldizzi's survey, as evidenced by the only circular tower still visible, and rich battlements running along the perimeter of the le mura and on the towers themselves. The first expansion occurred with Abbot Mansone (985/996), who inserted a tall central keep (about 30 meters) into the structure. Abbot Gerard (1111-1123) enlarged the fortress by inserting two minor towers flanking a mighty keep with a pentagonal base, the geometry of which is very reminiscent of more recent bastion systems. A small church, dedicated to the Annunziata, was also built inside, below which is a cistern connected to a rainwater collection system, which ensured the military garrison's self-sufficiency in the event of a prolonged siege. Fortification activity, mainly due to the numerous sieges for the attribution of abbey power, prompted Abbot Roffredo (1188/1210) to equip the fortress with a mighty wall system equipped with buttresses. In 1235, after demolition ordered by Frederick II of Swabia, the fortress was rebuilt, at the behest of Abbot Landulf (1227-1236), on the structure that has been preserved to this day.

Fig.10 Textured model of the Rocca: different views of the point cloud processed in Recap Pro software (Elaborated in collaboration with Pelliccio A., Saccucci M.)

4.3 Geometric-material survey.

The drone aerophotogrammetric survey.

The process of knowing and surveying Rocca Janula was extremely complex given its location in the Cassino geo-morphological context, extending along the slope of Monte Cassino. The Rocca is not fully accessible for the execution of a direct survey. Therefore, the possibility of surveying the property by means of UAVs allows to obviate the aforementioned problem. For the aerophotogrammetric survey campaign, an Unmanned Aerial Vehicle (UAV) DJI Mini 2 was specifically used, equipped with a 35mm f/2.8 lens capable of capturing images with size 3000x4000pxl. The flight plan design included 2 separate missions to cover the entire area. Specifically for each mission, the drone was flown manually without the use of keypoints or predetermined trajectories. Frames were captured according to suggested image acquisition techniques for digital photogrammetric

processing, ensuring overlap of 80 percent and overshoot of 60 percent [Saccucci et al., 2019]. Using a time-shot of 1 sec and a cruising speed of 1.2m/s, sufficient overlap between two consecutive frames was ensured. Thus, 346 high-definition (12Mpxl) images of the Rock were captured.
The photographs captured by the aerophotogrammetric survey were processed to create the photogrammetric digital model of the Rock. The photographs were filtered so as not to process overexposed or underexposed frames and out-of-focus images that affect photogrammetric processing. The open source software Meshroom was used to generate the three-dimensional photogrammetric model. The obtained model consists of a dense cloud of 6,388,782 points, geo-referenced with the WGS84 reference system. The model refers to an investigated area of about 100mx70m, with a measurement error of ±0.01m.

The model is of fundamental importance for understanding the exact geometry of the building envelope, but more importantly for recognizing its constituent elements and materials. In fact, the reconstruction of the outer envelope of the Rock, using meshing algorithms from the dense cloud, allows the textures to be mapped to obtain a photorealistic three-dimensional model. The latter turns out to be crucial as it virtualizes the complexity of the real object. Photorealism facilitates the reading and analysis of spatial relationships between components; the historical evolution that marked the object's life becomes legible, as well as its textural qualities, which often testify to the relationship between the object itself and the place. Photo-realistic chromaticity conveys information as a certainty of the datum, acquired from the state of art.

Fig.11 Rocca's point cloud processed in Recap Pro software
(Elaborated in collaboration with Pelliccio A., Saccucci M.)

The models created allow for different types of analysis. Taking advantage of the characteristics of the point cloud, in which each point characterized by three geometric coordinates x,y,z and three values related to RGB color, it is possible to differentiate the constituent materials of the investigated object. In particular, although difficult to distinguish with the naked eye, it is possible to highlight the original elements from those added in the most recent restoration work. In fact, as can be seen in the figure below, it is possible to discriminate the surfaces according to material and, by derivation, to distinguish the different parts that constitute the current state of the Rocca. The entire structure of the Rocca is of irregular masonry, of local calcarenite, except for the pentagonal tower,

Fig.12 Insertion of the point cloud in .rcp format within Revit software and subsequent processing of the model on the geometric basis obtained from the aerophotogrammetric survey. (Miele V.)

whose masonry consists of small regular ashlars of Roman travertine and mortar.

4.4 Rocca Janula three-dimensional H_BIM modeling.

The three-dimensional model of Rocca Janula, based on H_ BIM technology, was built using Revit software, in compliance with UNI 11337-"Digital Management of Information Processes in Construction," with a level of detail as built, and a dataset that includes in addition to the technological and geometric information of the elements, obtained with the geometric-material survey, also the archival documents, acquired during the historical-documentary survey phase.

The H_BIM model, in fact, uses as its geometric basis the point cloud obtained from the digital aerophotogrammetric survey, and is structured on the 'identification of the original components and what are the outcomes of the transformations undergone over the centuries. The point cloud itself consists of a set of elements accompanied by the relevant geometric and spatial information, which is fundamental for generating the model of the artifact with BIM modeling tools. In fact, the point cloud is equipped with geo-referencing markers that place it in the exact geographic location where the asset is located; by importing it into the BIM environment, the resulting model built on its basis is also correctly geo-referenced. To build the model, it was necessary to process the point cloud in ReCap Pro software, which is precisely used to create 3D models for real construction and infrastructure projects, exporting the .rcp file of the cloud and then importing it into Revit modeling software. Once the structural grid was built, the layers were defined (8 main layers were identified to optimize modeling). All the BIM objects to be modeled were set by paying attention to the LOD, geometric, material and relational characteristics. In addition to using the components already in the standard Revit database (walls, horizons, etc.), ad hoc families were created to conform the LOD to the as built layer so that all components of the fortress could be modeled, such as the entrance portal (fig.12).

Thus, the data contained in the model are numerous, as they define all information regarding each specific component of the architectural object, geographical location, geometry, properties of materials and technical elements, etc. Taking advantage of the potential of the BIM environment, in addition to obtaining a database that meets all the needs to intervene on the asset, thus containing all the information and data constituting the Rock, it is possible to produce very detailed graphical drawings, (plans, elevations, sections, views),

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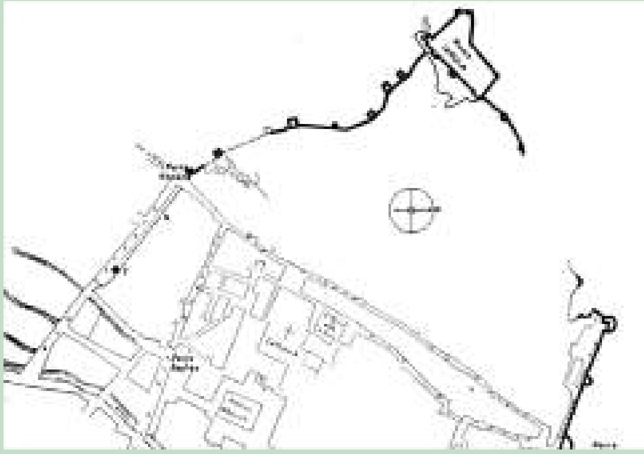
Typology	
Typo	Fortress
Name	Rocca Janula
Property	Public owner - municipality
Localization	
Municipality	Cassino, (FR)
Elevation	240 ca mt asl
Coordinates	41.4872 N - 13.8297 E
Consistency	
Surface	ca m^2
Volume	ca m^3
Masonry	Opera incerta - local calacarenite
Scarp	Yes
Conservation Values	
State of conservation	Restored/ Medium
Integrity	Medium
Authenticity	Medium
Historical Significance	High relevance

Cartographic references:
a | Carta Tecnica Regionale Numerica (CTRN) - Scala 1:5.000 - v. 2014
b | Drone sequence of architectural emergency (property of the author)

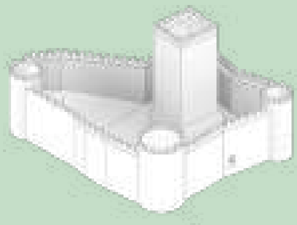
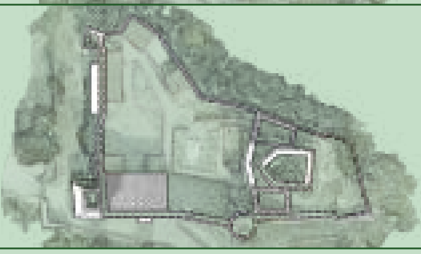
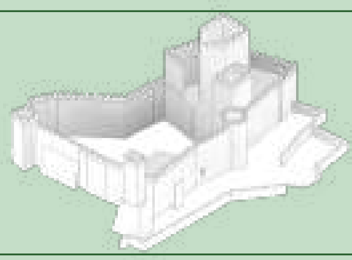

a


b


c

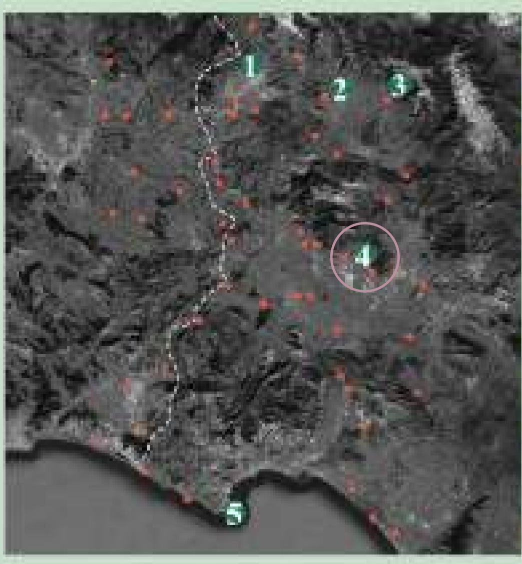

d

- **0**
- **X -XI sec** — Foundation according to medieval fortress layout and insertion of the defense walls, and the central keep
- **XI sec** — Extension of the walls and construction of the pentagonal central tower, and a small church
- **XIII sec** — The fortress was demolished in 1221 for the edict of Capua, promulgated by Frederick II of Swabia. The pentagonal tower was preserved as it was difficutl to demolish
- **XIV sec** — After being rebuilt, the fortress passed from the Swabian to the Aragonese, and in 1346 a strong earthquake caused numerous damages
- **1742** — During the reign of Charles III, in adastral census, the fortress appear in the State Property and is present in the Onciario Cadastre (Cadastre of the Kingdo of two Sicilies
- **XX sec** — Bombed durign WWII and then restored

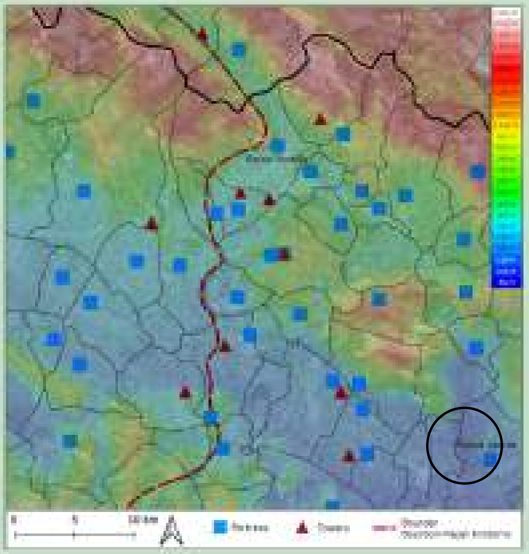
	DIGITAL PHOTOGRAMMETRIC MODEL	DIGITAL GEOMETRIC MODEL	
X Century			The original core has a typical medieval fortress layout. It is developed on an irregular quadrangle with circular towers.
XI Century			In the 11th century, as in most Latium fortifications, a central keep was added.
XV Century			During the early Renaissance the fortress is enlarged

a | Engraving, Montecassino and San Germano, in Annales, Iter Italicum litterarium, Mabillon, 1685-1686, Paris; **b |** S. Germano e Montecassino in Mabillon 1739; **c |** Drawing, "Convent du Mont Cassin et ville de San Germano, A. Soldé, 1857.; **d |** Plan, Urban layout of San Germano in its early days, Carettoni, 1960

GIS fortresses database



a



b

Maps are georeferenced in WGS84 UTM32N (EPSG 4236)

a | Case study identification with ID code, Rocca Janula is represented by "04"

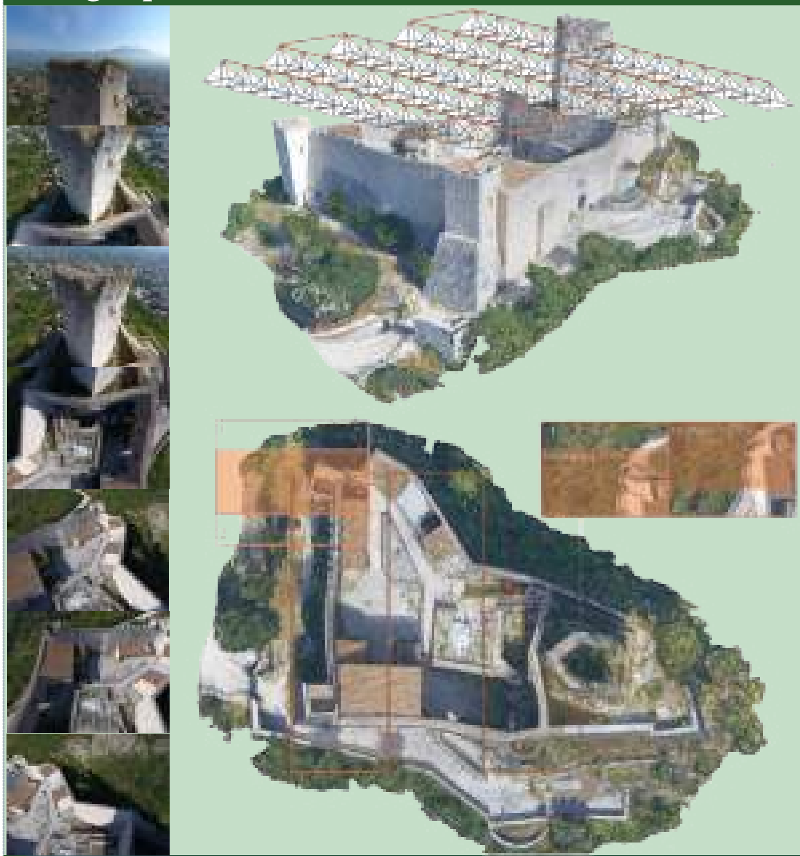
b | GIS symbolically shows the consistency of the fortification phenomenon and the orography of the terrain.

GIS shaft of fortified architecture in southern Lazio

The military characteristics of encastellation are evident in the Terra Sancti Benedicti territory controlled by the abbey of Montecassino, which in the second half of the 11th century, with the annexations of Turris ad Mare and Turris Gariliani at the mouth of the Garigliano River, experienced its greatest expansion.

In the GIS analysis, the boundaries of terra sancti benedicti, the mountainous area, the high working land and the territory of the duchy of Gaeta are identified.

Flight plan



Report

Drone DJI Mini 2

Date 15.09.2021
Time 15:00-18:00

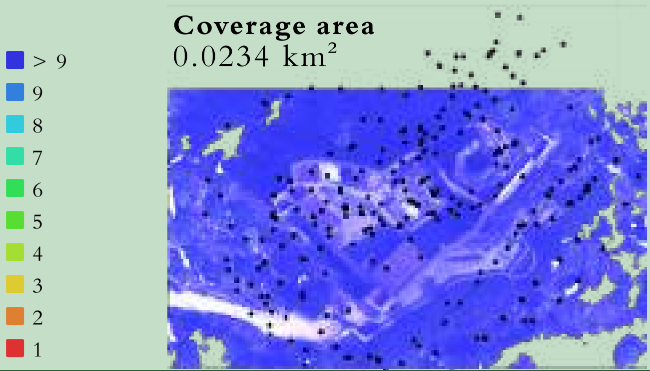
Number of images:	374
Flying altitude:	46 m
Ground resolution:	1.17 cm/pix

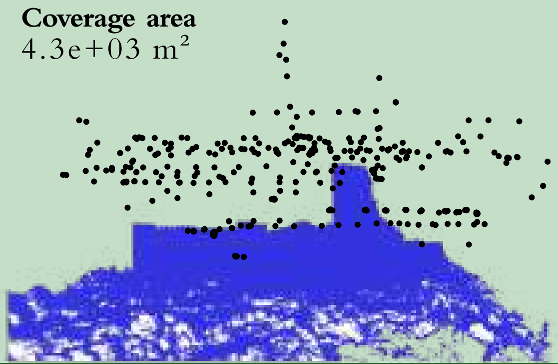
Camera stations:	373
Tie points:	326,945
Projections:	1,399,865
Reprojection error:	0.778 pix

Survey Data

Camera locations and image overlap

Camera Model	Resolution	Focal length
FC330 (3.61mm)	4000 x 3000	3.61 mm

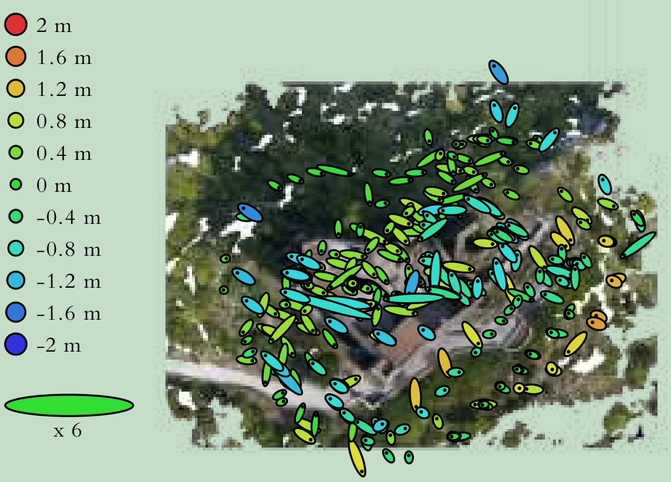




Camera Locations

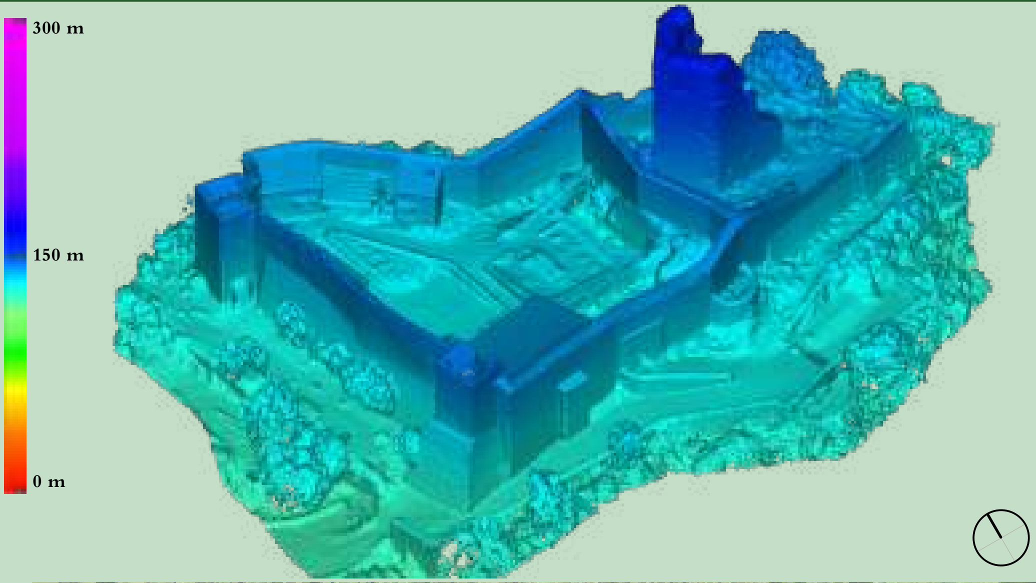
Camera locations and error estimates.

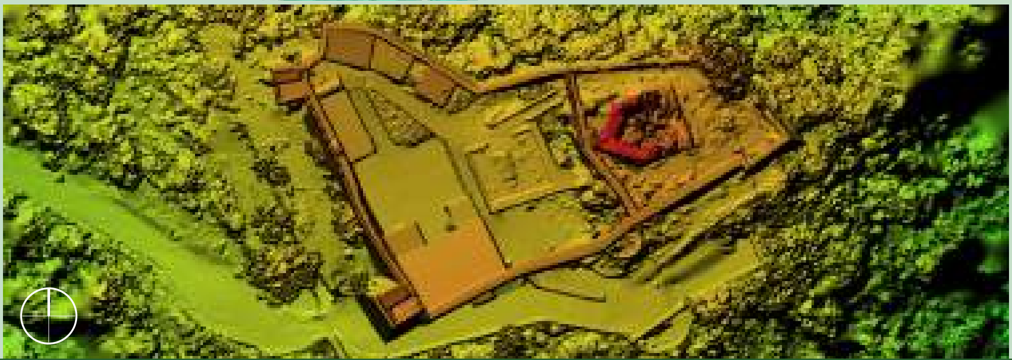
X error (cm)	58.0016	Total error (cm)
Y error (cm)	38.8207	95.5146
Z error (cm)	65.2059	
XY error (cm)	69.7942	



Estimated camera locations are marked with a black dot. Ellipses represent the error related to the cameras positioning after the resolution of the SfM process. The total error is the probability of distribution of the cumulative error, which here is less than 1%. The survey is well performed.

DEM_Digital Elevation Model

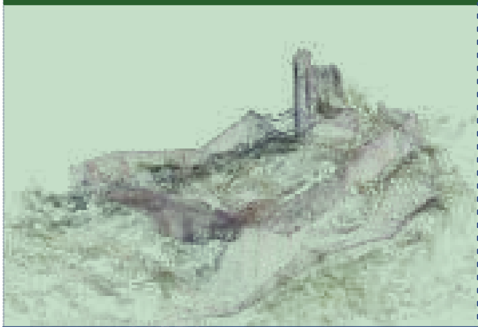




Stereo image pairs from an image collection are used to generate a point cloud representing the 3D locations for each of the connection points extracted from the images for which elevation data can be derived.

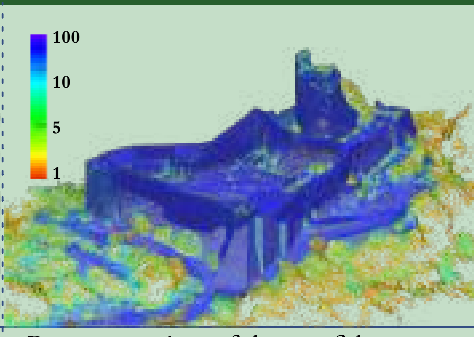
The derived elevation data can be visualized in a digital terrain model (DTM), which includes an estimate of the ground surface, and a digital surface model (DSM), which includes elevations of above-ground features.

Sparse cloud point



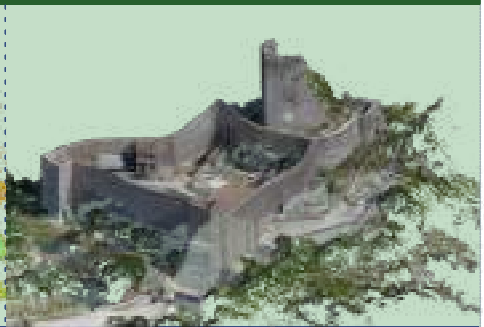
Key points resulting from the Structure from Motion process of camera alignment. First alignment step: the result is a sparse point cloud.

Confidence factor



Representation of the confidence factor, which indicates from how many frames the photogrammetry software records information and how accurate it is. Blue indicates the most accurate value (100%)

Dense cloud

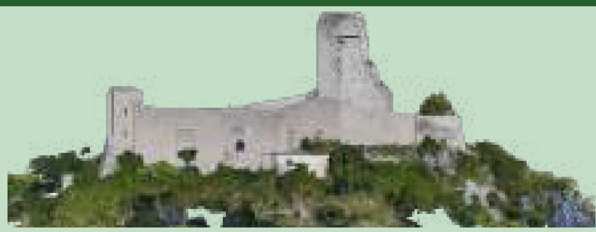


The dense cloud is characterized by a high density of points, providing a highly detailed and accurate spatial distribution of the features. It is the basis for creating 3D models and analyses.

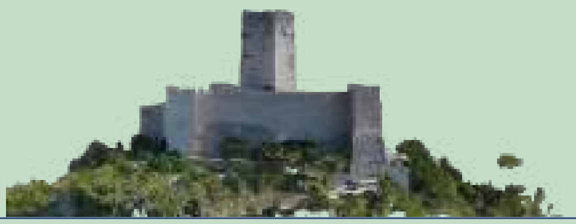
Tiled model

EST

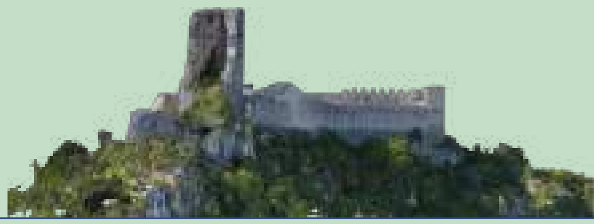
SOUTH



WEST



NORTH



The tile model is based on a dense point cloud and represents a high resolution, large-scale 3D model visualization. Its hierarchical tiles are derived from the original images, providing more information about the texture of the masonry.

SCAN TO BIM Procedure

INPUT

point cloud
.rcp file

point cloud
.rvt file

LINK

Rocca Janula .rvt file

Architectural model

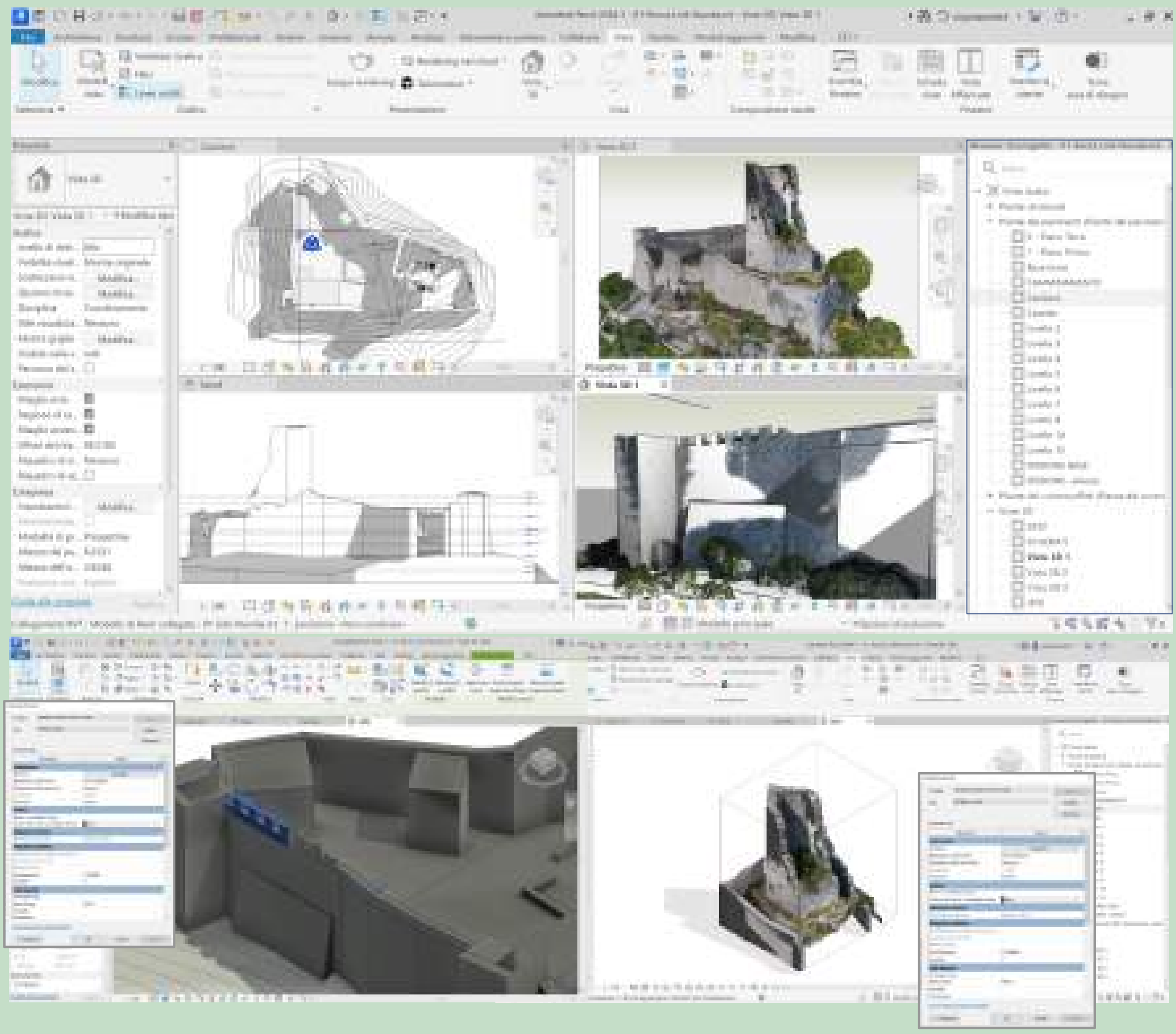
Features

(low)	(high)
LOG &LOI	LOG &LOI
Plugin in Revit	Revit families

OUTPUT

Structural Analysis	HBIM model

HBIM Parametric Modeling



_Definition of levels and design grids

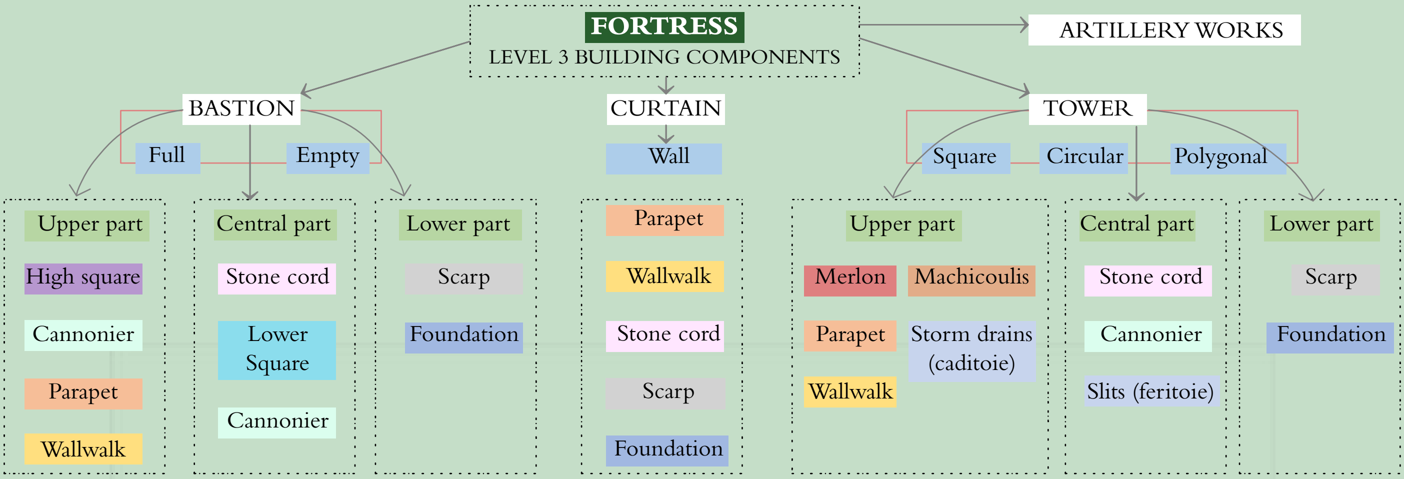
_Definition of design attributes (walls, floors, roofs)

_Modeling according to the point cloud: elaboration of the state of the art

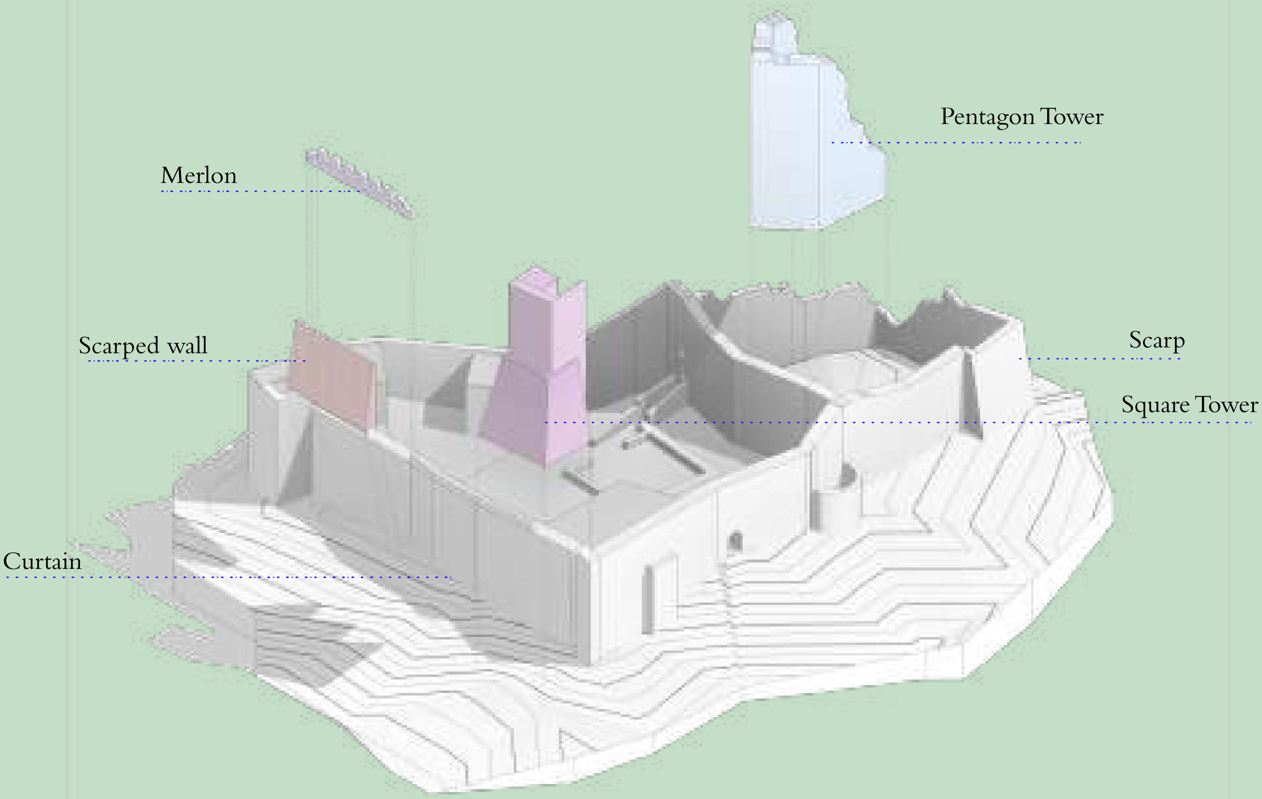
_Material and structural information of "wall, roof, floor" objects

_Modeling of local parametric families

Semantic segmentation and ontology construction (WBS)



Semantic enrichment of the HBIM model



Glossary extract - LOI

Merlon: masonry expedient of the upper parts of castle walls and towers. It consists of a symmetrical break in the wall, behind which the shooter shelters to deflect from opposing reaction. Different shapes were adopted according to place: triple-toothed, flower-shaped, pyramid-shaped, and semicircular (hence the ensemble of battlements was also called trine, lace, prominence). In the earliest feudal castles, the battlements were carved flush with the outer wall; later they were carved on projecting walls to allow more effective plumb defense. It was also built tapering, double-sloping; with curbs or comici to prevent arrows or thunderbolts from slipping through; with embrasures.

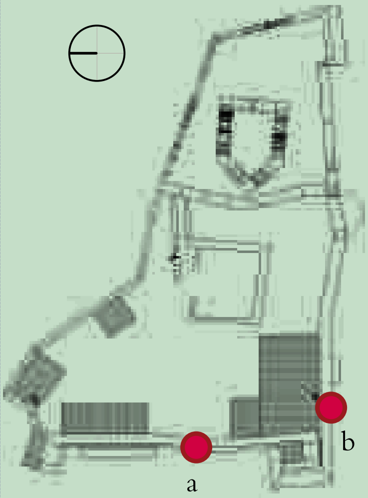
Curtain wall: Part of the wall between two successive towers or bastions. Essential element of any fortification, as it establishes the perimeter that must be defended.

Tower, (tour, Fr.) any high build ing raised above another, consisting of several stories, usually of a round form, though sometimes square or polygonal: a fortress, a citadel.

> **Tower-bastions**: in fortification, are small towers made in the form of batstions with rooms or cellars underneath to place men and guns in them.

Scarp: moat wall along the city wall or wall addition sloping at the base of the walls, to strengthen them and nullify the dead angles in front, to prevent the approach of mobile towers and the danger of mines.

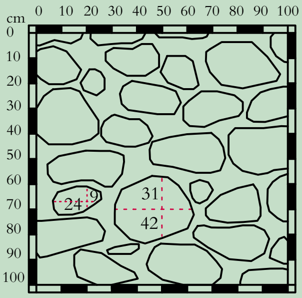
Samples identification for masonry analysis



Masonry consisting of natural resistant elements.

Masonry consists of stone elements bonded together by mortar. Stones obtained by felling rocks are laid in regular layers of uneven thickness, bonded by mortar.

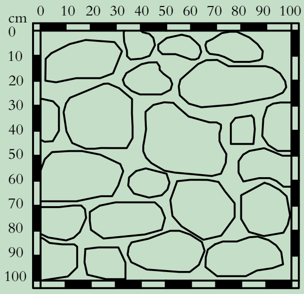
curtain wall (a)



	STONE	MORTAR
Area [m2]	0,8166	0,1834
Area [mm2]	816600	183400
%	81,7	18,3
Ratio Mortar/Stone	0,224	
Ratio solid-void:	0,22%	

The stone used is local calcarenite, in uncertain work with stone inserts of fair size but in good condition. the sample affects the first core of the castle.

curtain wall (b)



	STONE	MORTAR
Area [m2]	0,8184	0,1816
Area [mm2]	818400	181600
%	81,8	18,2
Ratio Mortar/Stone		0,222
Ratio solid-void:		0,22%

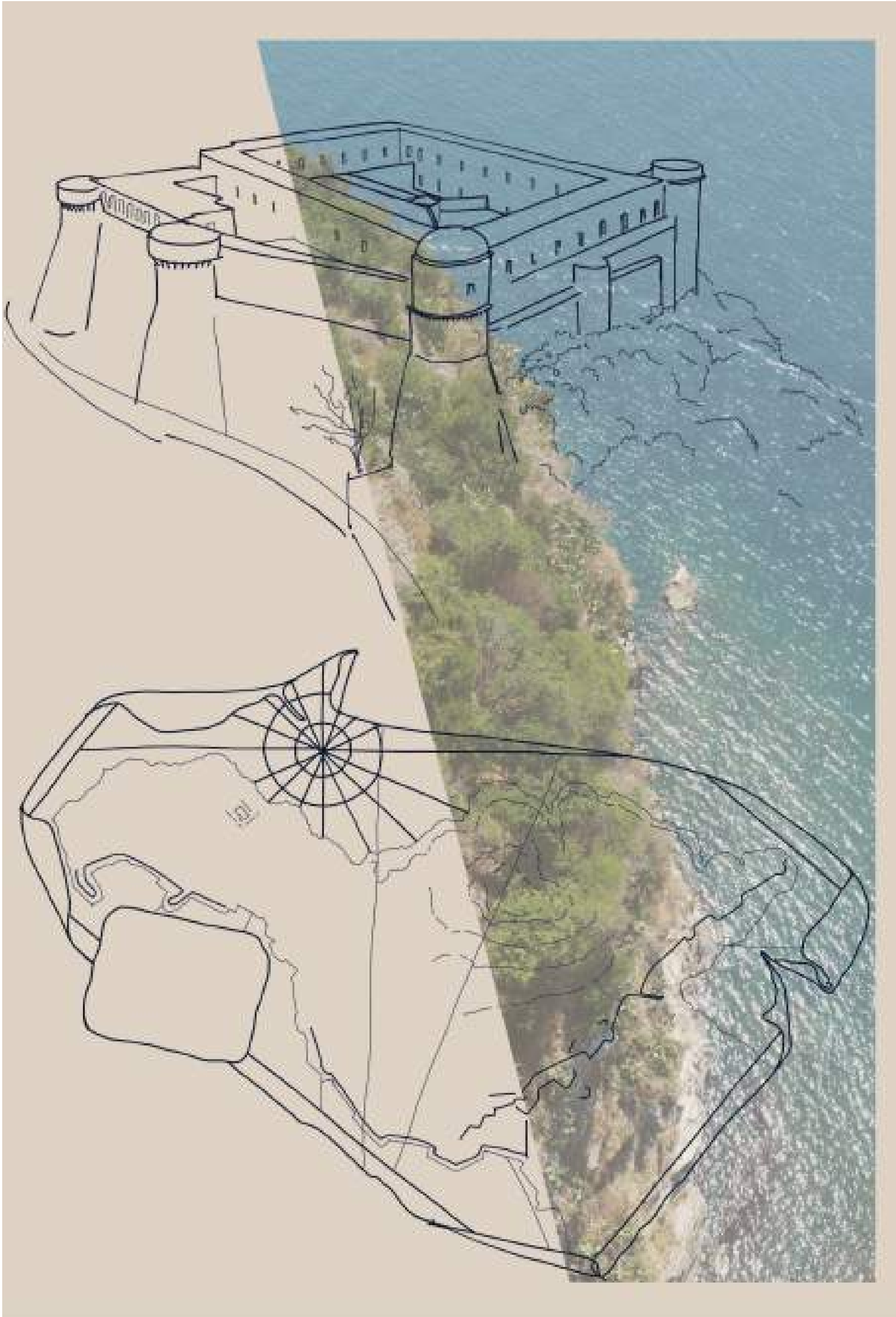
The stone used is local calcarenite, in uncertain work with stone inserts of fair size but in good condition. the sample affects the first core of the castle.

Synthesis Masonry features

	Material	Characteristics	Dimensions
Stone block	Lithology Sedimentary rock clastic (local calcarenite)	Superficial processing - roughing - squaring Color -Yellowish; - grey Shape - irregular	Block (hxb) min: 32x16 cm max: 57x26cm
	Mortar composition	Morphology and surface finish:	Thickness
Joint	aerial lime mortar (?)	-indented - degraded	Horizontal 3 - 30mm Vertical 3 - 10mm
Texture	Opera incerta		
Section	Nucleus undetected	Sack masonry	Total thickness 2m Nucleus: n.r
Description	Masonry with two faces occasionally connected with through elements (diatons) Made of local stone foundations, of small and large size, set to opera incerta with earth bedding and repointing		

Sample sheet of masonry technique. References to current standards for the parameters components of the sheet:

_NTC 2018 (Technical standards of construction)
_CIRCOLARE 21 gennaio 2019 , n. 7 C.S.LL.PP



Graphic elaboration by the author

View of San Casto castle, photo taken by drone by the author in collaboration with engineer Marco Saccucci.

Fig.13 The Bastion of Gaeta. On the edge the castle Angevin - Aragonese. ISCAG- F1 - 42/2757.

5. The Angevin Castle of Gaeta

The Angevin castle of Gaeta, an imposing monumental complex, has a high historical-artistic-landscape value and represents a powerful symbol of identity for the local community and beyond. Its origins probably date back to the sixth-seventh century, but the first specific information comes from the fortification interventions of the castle wanted by Frederick II of Swabia (1223-1227). The fortified structure of the Angevin period is part of the more extensive architectural system called the Angevin-Aragonese Castle, located on a rocky outcrop of Monte Orlando. The system is made up of two communicating buildings. The oldest, built by Charles of Anjou, has an irregular polygonal plan with mighty truncated-cylindrical towers located slightly further downstream. The other one, erected by Alfonso d'Aragona, conforms to a rectangular plan, surrounded by circular towers of different heights, among which stands an imposing keep. The Bourbon domination united the two castles intending to create one of the most majestic and well-equipped fortresses in Europe, located on the extreme offshoot of the Kingdom. The complex, which involves the two forts, thus becomes a model of extraordinary interest characterized by a modern fortification designed to enclose the entire peninsula of Gaeta

(Fig.1). Over the centuries, this mighty fortification, created to protect the territory and the kingdom's population, has become increasingly important from a military point of view, as a seat and as a prison activity carried out until 1990, determining a break with the city. Foreclosed to the peninsula, the city has had a linear urban development along the coast. The entire fortification system is the guardian of the memory of events that made Gaeta a protagonist in the history of the peninsula and represents an immaterial heritage, as well as an identity of great importance to be preserved, enhanced, and returned to citizenship. Based on digital surveys and historical maps, this research investigates the transformations undergone by the fortified complex, focusing attention on the Angevin castle and its intended use as a penal bath.

Fig.14 View of the Angevin – Aragonese castle, with the emerging tower Alfonsina. Printed in early 1900s.

5.1 Historical documentary survey

Monte Orlando, at an altitude of 171mt above sea level, dominates the gulf and the entire peninsula of Gaeta, considered, since its origins, a cornerstone for the defense of the Kingdom of Naples. "[...] Grande è l'interesse in cui l'ebbero sempre i Borboni, che riguardavano Gaeta come la chiave del Regno. Per mezzo di sole due porte si entra in Città, una è nel porto e si chiama mare, l'altra è nell'istmo e si appella terra. [...]" [1] [D. Pietro Rossetto, 1694]. Two fortified structures, known as the Angevin and Aragonese castles, were built on one of the foothills of the mountain in later times, occupying an area of over 14,000 square meters. (Fig.2) The mighty architectural structures, which characterize the two plants, are typical of the medieval fortifications, interspersed with towers that aimed to break the continuity of the wall and strengthen it. Following the architectural styles of the time, the set of towers presents a geometry articulated by several superimposed solids, a truncated cone, and a double system of cylinders. The last is a bracket that generates molding with a decorative function. In the fifteenth century, the advent of new weapons of war produced significant transformations in the fortified structures of our territory. In agreement with military engineers and architects such as Francesco di Giorgio and Francesco de Marchi, the "modern fortifications" included the insertion of bastions in the pre-existing architectural systems to improve defense against firearms.
Contrary to what happened in the rest of our territory, the Gaeta complex has not undergone such transformations. The reasons are to be found in the construction of a widespread defensive complex: a stronghold built between 1506 and 1538

1. "Great is the interest the Bourbons always had, who regarded Gaeta as the key to the Kingdom. One can enter the city through only two doors; one is in the port and is called the sea, and the other is in the isthmus and calls itself land". [D. Pietro Rossetto, 1694].

along the entire peninsula of the Gaeta by the will of Ferdinand the Catholic first and then of Charles V. The stronghold, which enclosed the two castles, was equipped with a bastion wall that extended for about 3 kilometers along the coast, effectively separating the peninsular belt from the mainland (Figs. 2; 3 and 4). "[...]Tutta la città è fortezza, e trà l'altre cose, che la rendono fortissima, è il castello; ed oltre a questa Rocca v'è la torre, detta Orlando sita nella sommità del Monte. Il mentovato castello, fu fabbricato da Rè Alfonso d'Aragona circa gli anni 1440 e dal Rè Ferdinando fu cinto di fortissime mura. Poi l'Imperador Carlo V cinse la città tutta d'altissime mura. È racchiusa Gaeta da due sole porte, che si custodiscono con grande diligenza.[...]"[D. Pietro Rossetto, 1694][2]. In four centuries, it has grown and improved with the inclusion within military structures, which responded to the increasingly advanced war techniques, such as powder magazines, batteries, trenches, and tunnels, overcoming differences in height and drilling hills that characterize the articulated orography of this territorial area. Three powder cases, called Carolina, Ferdinando, and Trabacco, are still preserved in good condition and clearly visible today.

2. "The whole city is a fortress, and among the other things that make it very strong is the castle; in addition to this fortress, there is the Orlando tower located on the top of the mountain. The castle mentioned above was built by King Alfonso of Aragon around the 1440s, and solid walls surrounded it by King Ferdinando. Then Emperor Charles V surrounded the whole city with very high walls. Gaeta is enclosed by only two doors guarded with great diligence". [D. Pietro Rossetto, 1694].

The battery, called annular due to its geometric plan configuration that surrounds the mausoleum of Lucio Mugnazio Planco, Roman military and republican politician, was built to replace the cannons, now obsolete. The plant is still visible even if the architectural remains are small. Its construction dates back between the last siege of the fortress (1860/1861), which represents the disappearance of the Kingdom of the two Sicilies, and the unification of Italy. The formation of the kingdom of Italy did not change the role and characteristics of the city of Gaeta until the end of the Second World War, whose bombings contributed to the cancellation of historical testimony, its stronghold a unicum on our territory. The few traces that survived the bombings were then definitively erased by the construction of the Caboto seafront.

<u>The Angevin castle from fortification to penal bath</u>

The military function of the entire fortress was also evident by the custodial use of the two fortresses, particularly the Angevin castle, which has been used as a penal bath since the Middle Ages (Fig. 3). The idea of an autonomous prison architecture was slow to develop. From ancient times it was necessary to use the most disparate places, such as wells, cisterns, caves, and natural ravines used for detention. In the Middle Ages, the undergrounds of palaces and castles were used for the first

Fig.15 Photogrammetric survey from a drone of the Angevin castle that highlights its mammoth architectural structure. (Elaboration by the author in collaboration with Eng. Marco Saccucci)

time, particularly the keeps, giving rise to the "penal bath" by applying the motto of Ulpiano "carcer enim ad continendos homines, not punendo a berri debet." The custodial use of the Angevin castle follows, as for the fortifications surrounding it, the evolution of the concept of imprisonment and punishment. Initially, the prison was supposed to be the place to enclose the prisoner pending trial, death penalty, or hard labor. Later it becomes a place to atone for one's sentence. The penal bath of Gaeta became, in fact, over the centuries of the second class, or the place where the inmates, condemned to forced labor, carried out the demanding tasks wearing an iron circle on their feet. These places, now known as Bourbon cells, are located on the northwest side of the castle, overlooking the sea. The fortress was subsequently enlarged as a detention facility by modifying some rooms above the Chapel of San Teodoro on the north side. This arm is now known as the Piedmontese Cells because it was intended for former officers after the Savoy's advent. Over time, additional rooms have been used as military penitentiaries. Some dormitories were defined, A-B-C-D, conceived as open environments but intended to accommodate those who had not complied with military obligations, such as Jehovah's Witnesses. (Fig. 4).

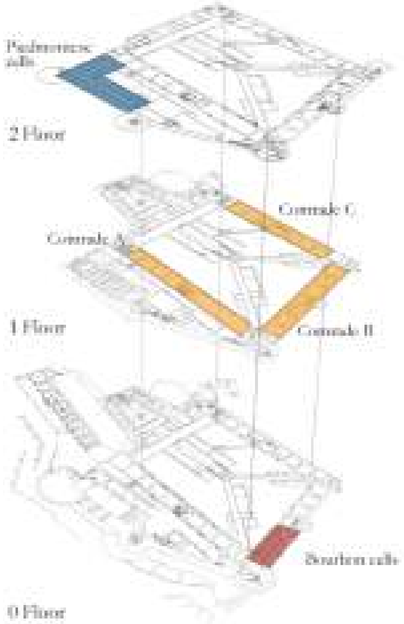


Fig. 16 The graphic elaboration of the Angevin castle layout shows the rooms' location intended for prisoners. (Elaboration by the author)

The graphic elaboration (fig.4.) of the Angevin castle layout shows the rooms' location intended for prisoners. The Bourbon cells, represented in red, are located on the mezzanine floor. The Piedmontese cells, represented in blue, are located on the second floor; the dormitories A-B-C, represented in yellow, occupy the various levels of the complex and are located along the sides of the main quadrilateral.

The entire Angevin fortress is known for having detained two leading figures in Nazi history in Italy, Herbert Kappler, guilty of the massacre of the Fosse Ardeatine in Rome, and Walter Reder, one of the instigators of the Marzabotto and Sant'Anna massacres. by Stazzema. Their stay in the facility lasted about thirty years, but both led a privileged life compared to the other inmates. Their cells, in correspondence with the B dormitories, were huge and equipped with every comfort. Now the Angevin castle is home to the University of Cassino and Southern Lazio, which holds it on perpetual loan. From an architectural point of view, it has an interesting internal elevation development that follows the land's orography and responds to the typical organization of medieval fortifications. Contrary to the Aragonese castle, which preserves the royal residence rooms, it lacks decorations or valuable architectural elements. Only the internal garden of Maria Sofia of Bavaria is preserved, representing the filter between the two structures of the complex and the royal chapel of Francis II of Bourbon. The chapel, located in the westernmost tower and recognizable by the presence of a lowered dome that closes the tower itself, presents a worrying crack pattern and the presence of colored plaster that suggests a decorative apparatus that is now completely lost. The structure has undergone numerous transformations, all aimed at adapting to the new needs required by the military penitentiary. The construction, for example, of the connecting corridors between the dormitories, in the courtyard of the main quadrilateral, was made in more recent times and had a mixed construction system in reinforced concrete and iron. The rest of the structure, except for a few rooms, is heavily degraded, although the wall system of elevation of the towers and the wall system is in a good state of conservation, except for the chapel. The military penitentiary activity was definitively abandoned in 1990.

<u>The Bourbon cells</u>

The oldest cells are the so-called Bourbon Criminal Bath, which remained in use until the 1950s: 12 cells of a few square

meters, without windows, branch out along a corridor. Equipped with stone beds and pillows, a ring or chain embedded in the floor to keep the prisoner tied up, and a slit under the bed to place the bucket, reminiscent of medieval galleys. Each cell was also closed with wooden doors and was utterly devoid of light to exacerbate the punishment further.
Fragments of colored plaster provide essential information on the original colors of the environment that go towards Pompeian grayz-red tones. This duotone that does not go beyond one meter from the floor is typical of government buildings [Ancora, 2021]. At the bottom was the environment of the "beating" practice, also of an ancient medieval heritage.

Fig. 17 Bourbon cells. Narrow hallway and the stone beds and pillows. (Author's photos)

<u>The Piedmontese cells</u>
In the other wing of the fortress, located on the second level above ground, there is the so-called ex-officers' arm with the Piedmontese cells, in use from 1901 until 1990, after the advent of the Savoy and until the closure of the prison: about ten square meters, with wolf-mouth windows, which precluded the view of the sea, valid only for the entry of air, with a table and a wooden bed. The doors retain the Savoy blue paint, a color very dear to the Piedmontese family since the fourteenth century. After a ladder, the inmates reached a small circular terrace intended for air time under the close surveillance of the armed guards [Ancora, 2021]. The molding of the circular tower served as a parapet, so high as to preclude the view of the sea (Fig. 6). With the help of historical and critical iconographic apparatuses, this work aims to organically reconstruct the vicissitudes of the Angevin castle of Gaeta, which is part of a larger fortification complex. A unique system of its kind for several reasons: a) due to the close presence of two fortresses built in later periods but then used as an architectural unit; b) for the construction of a stronghold with modern bastion systems and numerous other increasingly modern military structures; c) due to its particular intended use, a penal service, which remained active until 1990.
This structured analysis of the history of the castle represents the first step for a more complex and detailed analysis necessary to activate a process of enhancing a highly identifying asset for the local community and beyond.

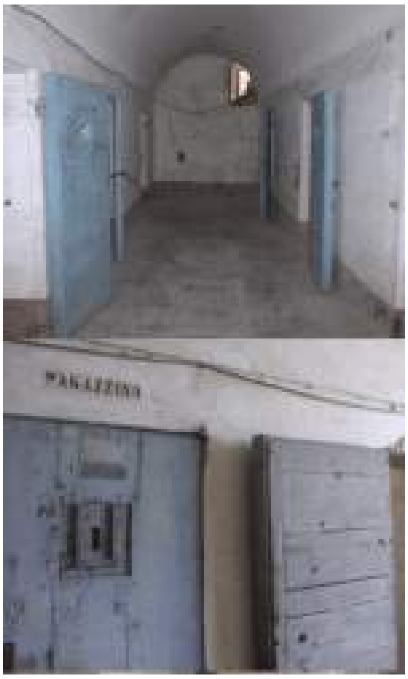


Fig.18 Piedmontese cells. The wooden doors in the original color, numerous writings that identify the intended use of the rooms are still preserved. (Author's photos)

5.3 Georeferenced Cataloguing in GIS

The application of Geographic Information Systems enables the fortification sites of Southern Lazio to be documented in space. By georeferencing the catalog of architectural remains, topographic information, and historical cartography, one obtains a uniform spatial platform for integrated analysis. GIS technology allows the precise location of each fortification and enhances the understanding of the territorial dynamics, routes of access, and strategic visibility that played a major role in determining their location. This georeferenced catalog will provide the foundations for subsequent investigations, enabling comparative analyses across fortified sites and regions. Table 3 shows the case study identification code as cataloged in the GIS database, while it delineates and identifies the historical path from the Gaeta gulf to the inland reaching Sora, Alvito and Vicalvi.

5.4 Geometric-Material Survey

A crucial element in the documentation process is the geometric-material survey, designed to capture the precise physical attributes of the fortifications. This involves measuring dimensions, materials, and construction techniques. By combining conventional surveying methods with advanced technologies such as drone photogrammetry, high-resolution data are produced, ensuring meticulous documentation of architectural details. Drone-based photogrammetry makes documentation particularly possible for areas that are otherwise inaccessible, thus maintaining the completeness of site recordings. These indeed get an upgrade with Structure from Motion techniques, which convert image sets into three-dimensional digital reconstructions that also preserve geometric accuracy and allow for in-depth visual analysis. These digital models are basic for the study of both the current state of the fortifications and their original form. For this reason, they are fundamental to the restoration and conservation process. The models and related results are shown on boards 4 and 4b.

5.5 HBIM for Three-Dimensional Ontological Modeling

The final step is the realization of the three-dimensional ontological model by using HBIM. In this step, the data acquired from the geometric-material survey and from photogrammetry are combined in a single digital model. The HBIM framework allows inclusion of historical, material, and construction data, thus supporting not only architectural analysis but also the simulation of various restoration scenarios. This is a dynamic model, which is continuously updated as new data become available and more research is done; results of modeling are presented on boards 5 and 6.

5.6 Further Analysis

Put together, these first sets of procedures, along with the outcomes stored in the spatial and architectural databases, form a minimum foundation for further analysis. In particular, the GIS database allows the performance of spatial analyses that considerably enrich the understanding of territorial dynamics and the relationships between sites. Furthermore, as is shown in Chapter 4, Paragraph 7, the application of SfM techniques enables dimensional analysis. These methods have been proven not only to create very accurate volumetric models but also structural insight, such as those represented in Table 7. As the results indicate, SfM may contribute to wider discussions regarding construction methods and the stability of the examined structures, allowing this technique to go beyond mere documentation into diagnostics.

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14. Saccucci M., Miele V., Pelliccio A., (2022), UAVs for the analysis of geometrical deformation of fortresses and castles. The case study of Sora Castle. In Parrinello S., Barba S., Dell'Amico A., di Filippo A., (eds) Prospettive Multiple. Studi di Ingegneria, Architettura e Arte of Pavia University Press. ISBN 978-88-6952-159-1, pp. 58-65

Typology	
Typo	Fortress
Name	Angevin castle, Gaeta
Property	Public owner – loan for perpetual use to the University of Cassino
Localization	
Municipality	Gaeta, (LT)
Elevation	20 ca mt asl
Coordinates	41.2126 N – 13.5697 E
Consistency	
Surface	10,257 m^2
Volume	ca m^3
Masonry	
Scarp	Yes
Conservation Values	
State of conservation	Medium/ Partly restored
Integrity	High
Authenticity	High
Historical Significance	High relevance

Cartographic references:
a| CTR Comune di Gaeta, Castello Aragonese, Foglio 415163. Scala 1:5000, anno 2020, Geoportale Regionale Lazio;
b|Drone sequence of architectural emergency (property of the author)

a

b

c

d

VI – VII sec
Foundation of the castle due to its strategic location on the Tyrrhenian Sea

0

IX – XII sec
The Normans conquered Gaeta in the 11th century, incorporating it into the Kingdom of Sicily

1223 – 1227
The first specific information comes from the fortification interventions wanted by Frederick II of Swabia

XIII sec
The Angevin Castle gained prominence during the reign of Charles I of Anjou.

1506 – 1538
Construction of a stronghold along the entire peninsula of Gaeta by the will of Ferdinand the Catholic first and then of Charles V.

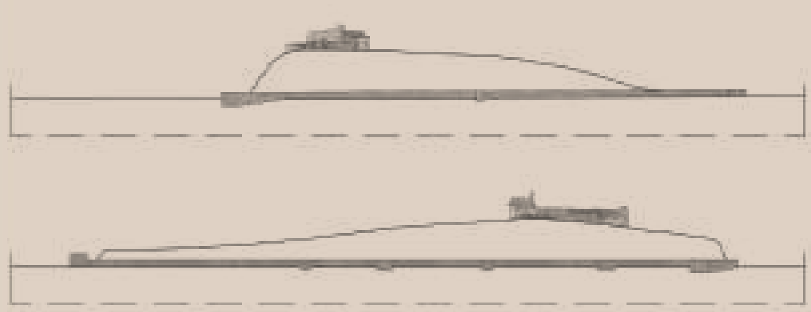
XX sec
The Angevin fortress detained two leading figures in Nazi history, guilty of the massacre of the Fosse Ardeatine in Rome, and Marzabotto and Sant'Anna di Stazzema.

XX sec
The military penitentiary activity was definitively abandoned in 1990

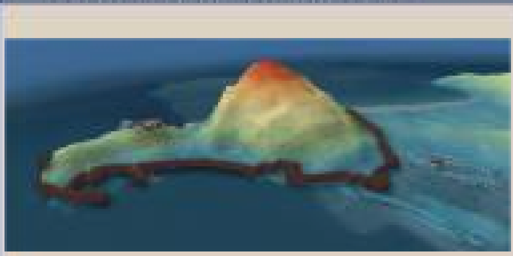
XV Century

OVERLAY HISTORICAL MAP AND GIS

2D RECONSTRUCTION



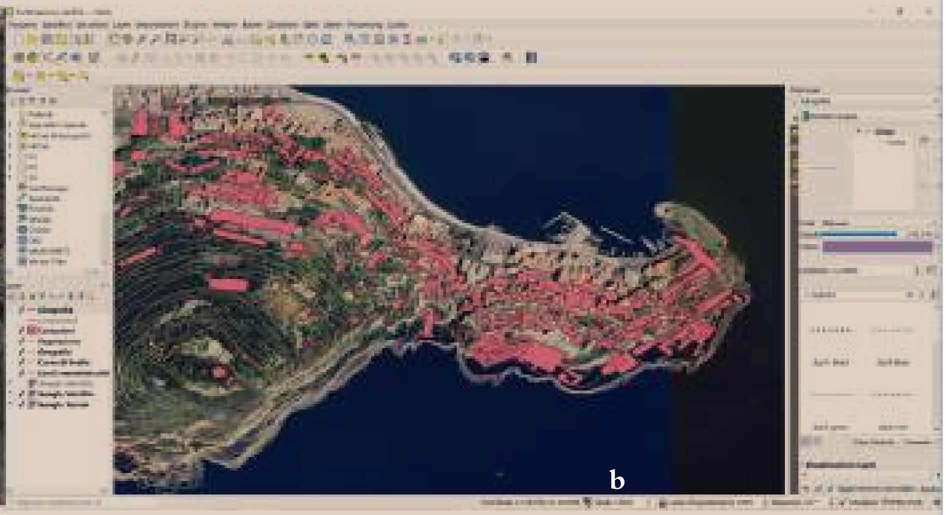
DIGITAL RECONSTRUCTION



In the XV century, the advent of new weapons of war produced significant transformations in the fortified structures of our territory. The "modern fortifications" included the insertion of bastions in the pre-existing architectural systems to improve defense against firearms. the Gaeta complex has not undergone such transformations. The reasons are to be found in the construction of a widespread defensive complex,built between 1506 and 1538 along the entire peninsula of the Gaeta. The stronghold, which enclosed the two castles, was equipped with a bastion wall that extended for about 3 kilometers along the coast, effectively separating the peninsular belt from the mainland

References:
a | 1675. [s.n.]Carte particuliere de la rade et du mouillage de Gaiette avec le trait en petit de la ville; b | 1710. Planta de Gaeta, [s.n.] carta, Bibliothèque nationale de France, départment Cartes et plansa; c | 1764. Joseph Roux – Ville et Baye de Gaète (Gayètte). Marseille; d | 1860. Pianta della Piazza di Gaeta, Napolitan Civil Engineers Agency;

GIS fortresses database



Maps are georeferenziate in WGS84 UTM32N (EPSG 4326)
a | Case study identification with ID code, Angevin castle of Gaeta is represented by "05"
b | GIS shows the consistency of the construction in the Gaeta territory and the orography of the terrain.

GIS overlay | Historical paths identification

To a historical-topographical examination of southern Latium within the chronological limits of the Middle Ages, the situation of the territory between Sora and Cassino appears interesting, with the presence of an extensive and articulated system of fortifications presenting unitary characteristics.

In this part of southern Latium, three zones can be identified:

1) a western coastal band, whose defense works soon pivoted on the fortress of Gaeta;

2) an intermediate belt, whose extensive fortifications exercised control over the Liri valley and the routes to the coast;

3) the eastern zone, neuralgic for communications to the Terra di Lavoro.

Three zones that corresponded to the main routes to the Kingdom of Naples.

c | The routes from the interior to the Gaeta stronghold, indicating the most important passes.

Flight plan

Report

Drone DJI Mini 2

Path n.1

Path n.2

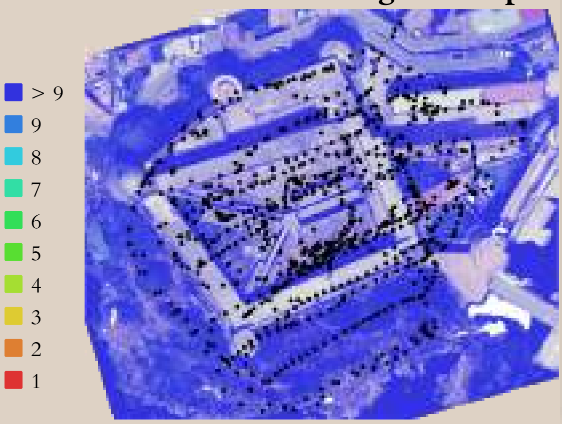
Date 18.07.2022
Time 15:00-18:00

Number of images:	940
Flying altitude:	41.9 m
Ground resolution:	1.16 cm/pix

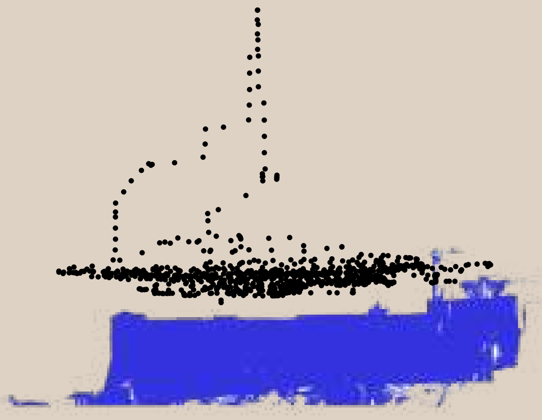
Camera stations:	938
Tie points:	505,353
Projections:	3,112,043
Reprojection error:	1.19 pix

Survey Data

Camera locations and image overlap.



Coverage area 0.0395 km²



Coverage area 6.41e+03 m²

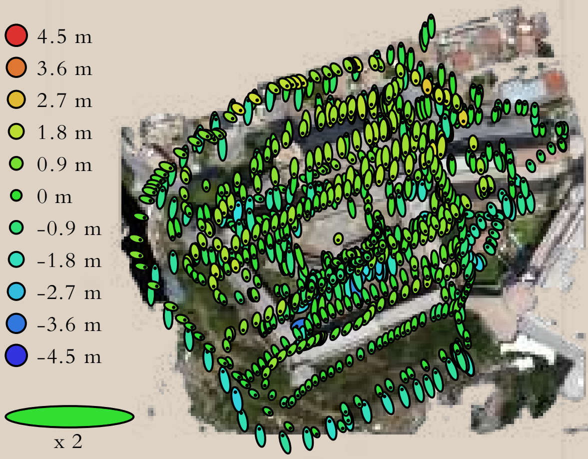
Camera Model
FC7303 (4.49mm)

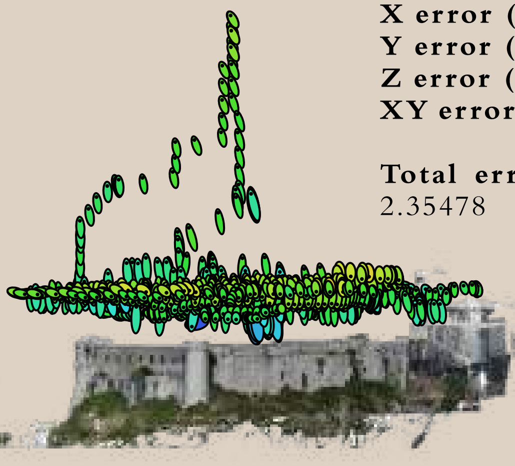
Resolution
4000 x 3000

Focal length
4.49 mm

Camera Locations

Camera locations and error estimates.



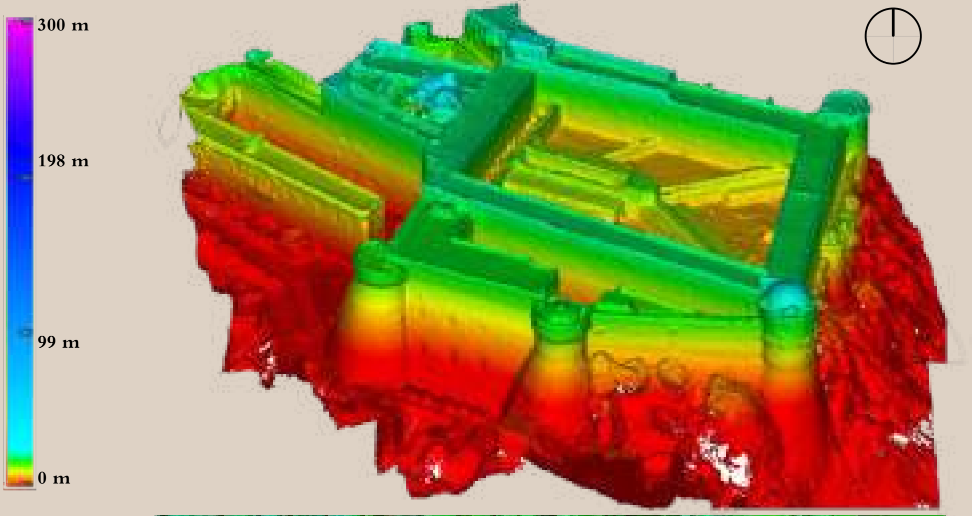


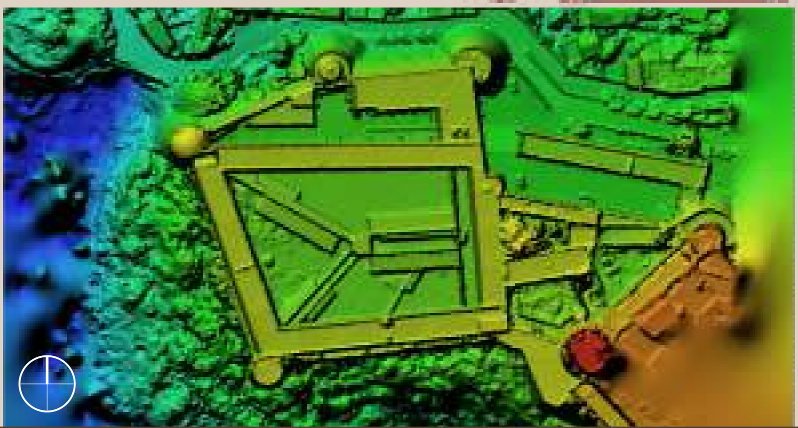
X error (m)	0.489167
Y error (m)	2.0493
Z error (m)	1.0517
XY error (m)	2.10687

Total error (m)
2.35478

Estimated camera locations are marked with a black dot. Ellipses represent the error related to the cameras positioning after the resolution of the SfM process. The total error is the probability of distribution of the cumulative error, which here is less than 2%. The survey is well performed.

DEM_Digital Elevation Model





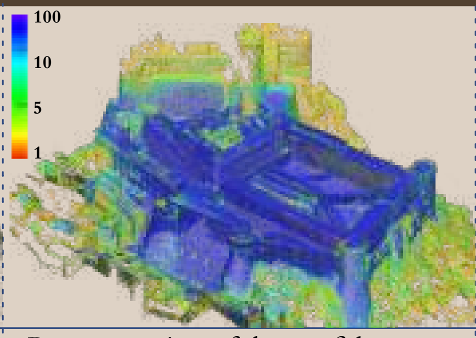
Stereo image pairs from an image collection are used to generate a point cloud representing the 3D locations for each of the connection points extracted from the images for which elevation data can be derived.

The derived elevation data can be visualized in a digital terrain model (DTM), which includes an estimate of the ground surface, and a digital surface model (DSM), which includes elevations of above-ground features.

Sparse cloud point

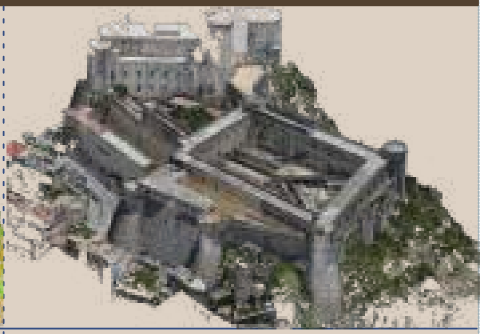
Key points resulting from the Structure from Motion process of camera alignment. First alignment step: the result is a sparse point cloud.

Confidence factor



Representation of the confidence factor, which indicates from how many frames the photogrammetry software records information and how accurate it is. Blue indicates the most accurate value (100%)

Dense cloud



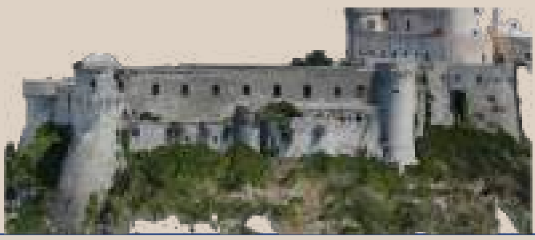
The dense cloud is characterized by a high density of points, providing a highly detailed and accurate spatial distribution of the features. It is the basis for creating 3D models and analyses.

Tiled model

EST

SOUTH

WEST



NORTH

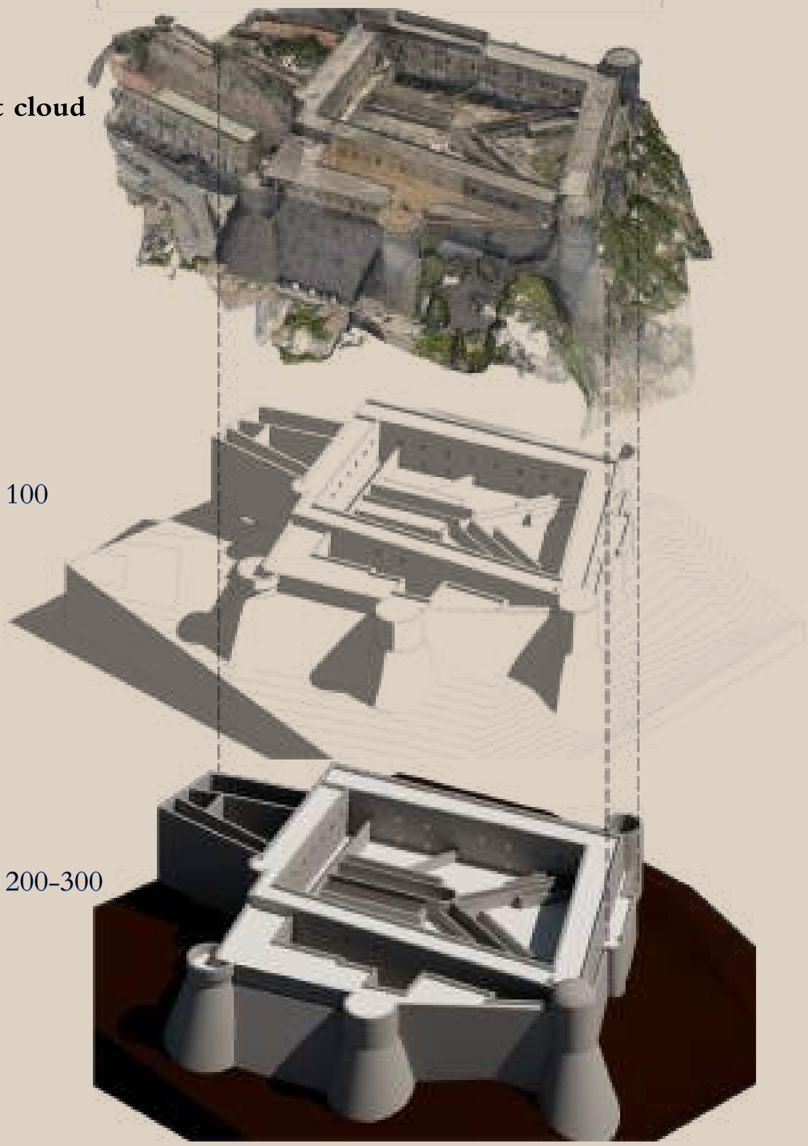
The tile model is based on a dense point cloud and represents a high resolution, large-scale 3D model visualization. Its hierarchical tiles are derived from the original images, providing more information about the texture of the masonry.

SCAN TO BIM Procedure

point cloud

LOD 100

LOD 200-300



INPUT

point cloud
.rcp file

point cloud
.rvt file

LINK

Angevin Castle .rvt

Architectural model

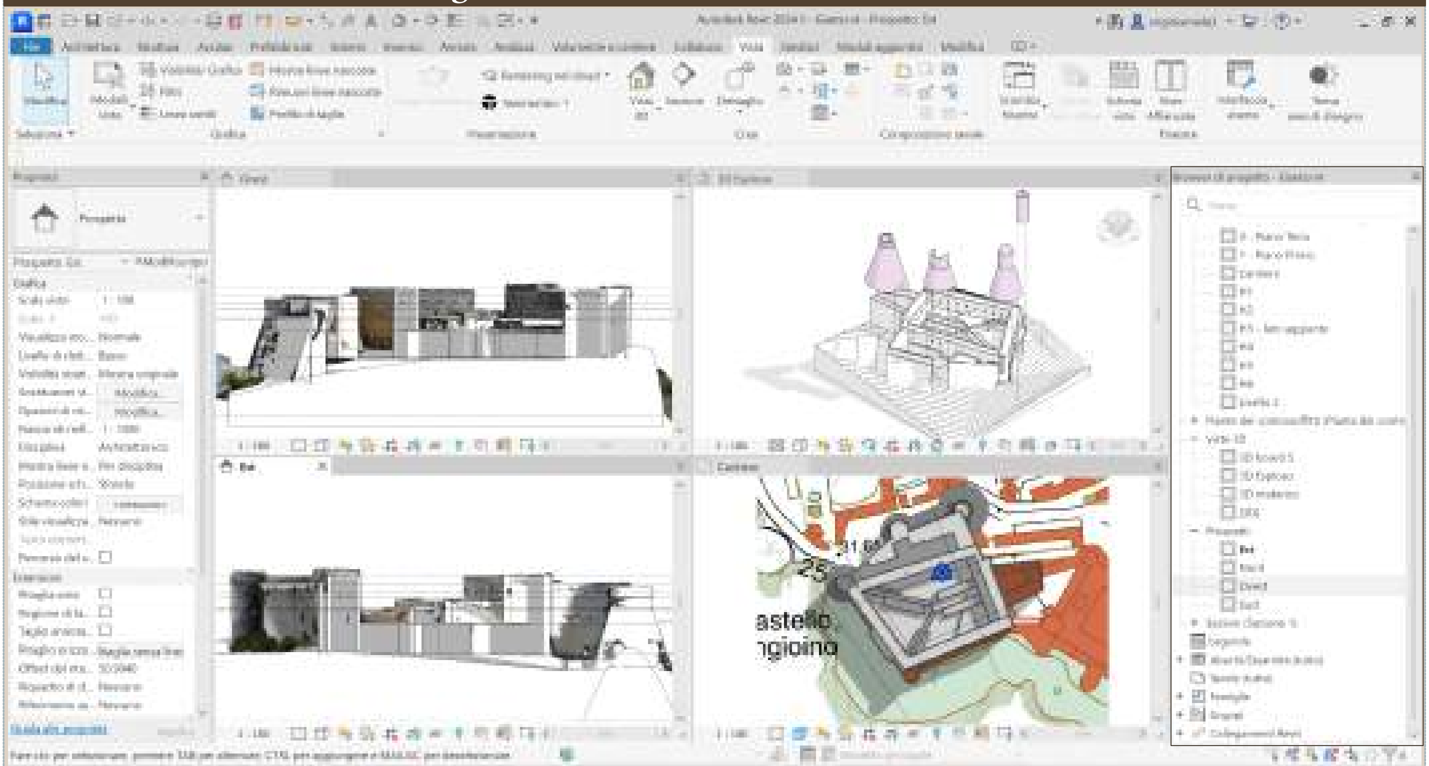
Features

(low) LOG &LOI	(high) LOG &LOI
Plugin in Revit	Revit families

OUTPUT

Structural Analysis	HBIM model

HBIM Parametric Modeling



_Definition of levels and design grids

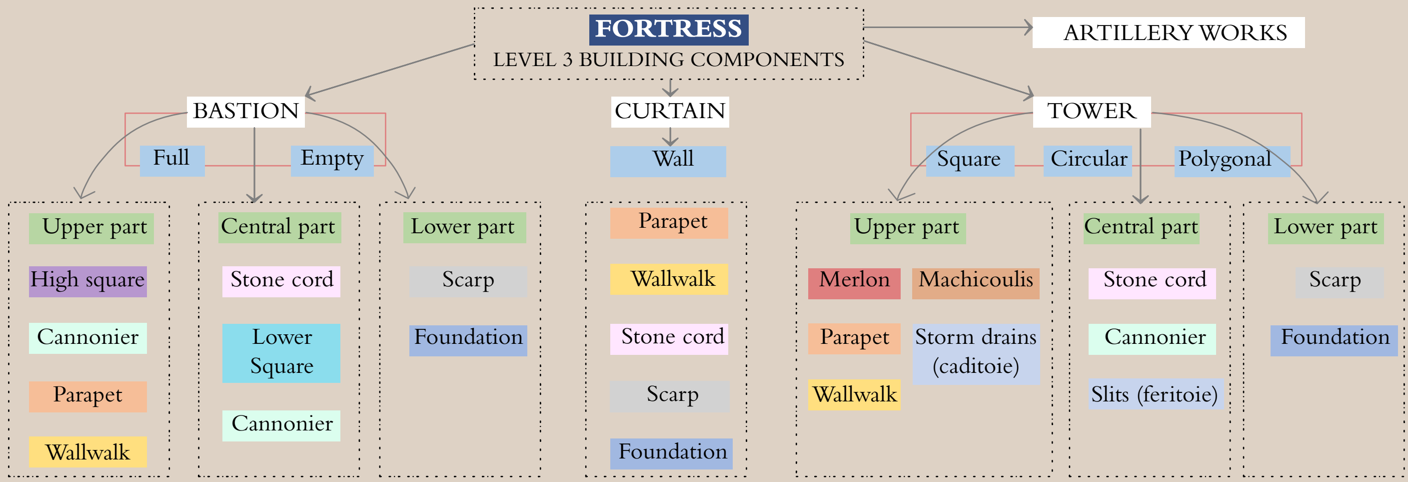
_Definition of design attributes (walls, floors, roofs)

_Modeling according to the point cloud: elaboration of the state of the art

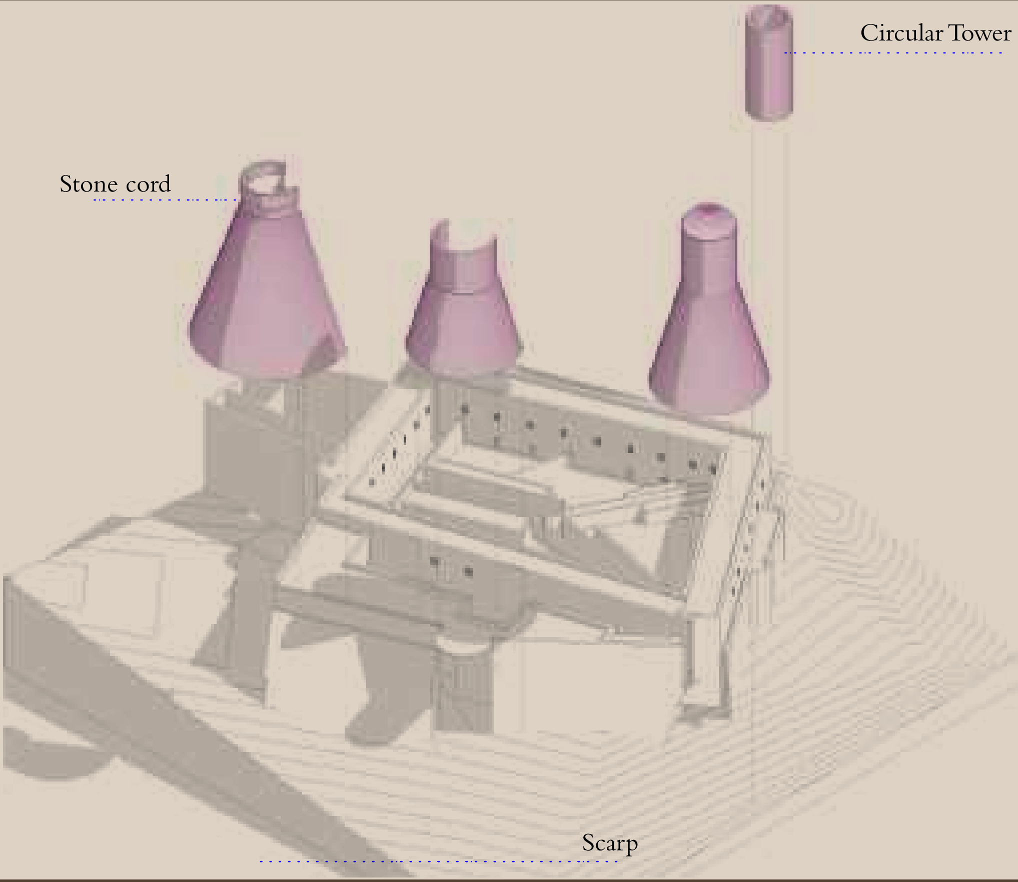
_Material and structural information of "wall, roof, floor" objects

_Modeling of local parametric families

Semantic segmentation and ontology construction (WBS)



Semantic enrichment of the HBIM model



Glossary extract - LOI

Louver: Compartment made between the spouts (v.) of the projecting apparatus. Stones, darts, or boiling water, oil, or pitch were plunged on the assailants from this compartment.

Curb (or Stone cord): architectural expedient adopted on the outside of parapets or battlements to prevent slipping or ricocheting of projectiles launched from below.

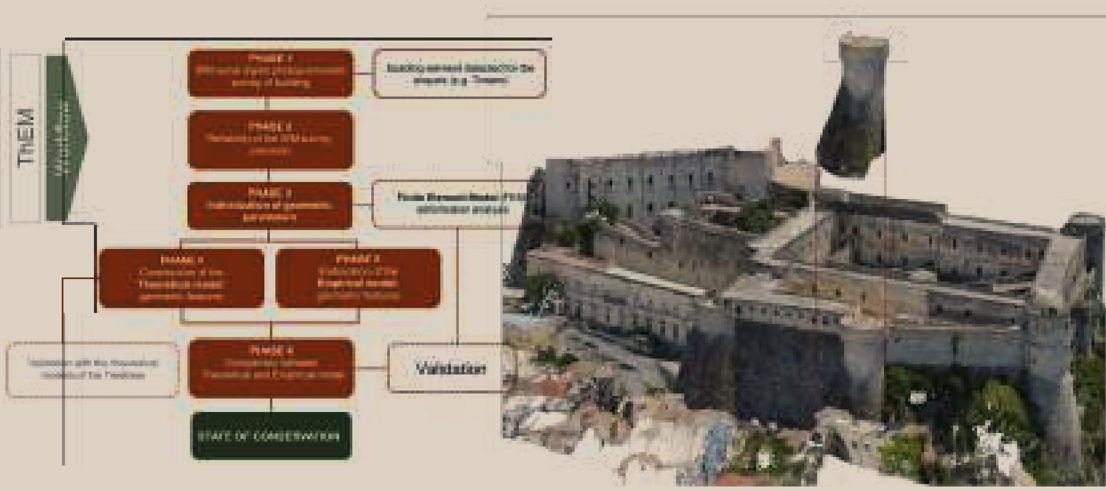
Cortina: Part of the wall between two successive towers or bastions. Essential element of any fortification, as it establishes the perimeter that must be defended.

Tower, (tour, Fr.) any high build ing raised above another, consisting of several stories, usually of a round form, though sometimes square or polygonal: a fortress, a citadel.

Tower-bastions: in fortification, are small towers made in the form of batstions with rooms or cellars underneath to place men and guns in them.

Scarp: moat wall along the city wall or wall addition sloping at the base of the walls, to strengthen them and nullify the dead angles in front, to prevent the approach of mobile towers and the danger of mines.

SfM survey and identification of the architectural elements

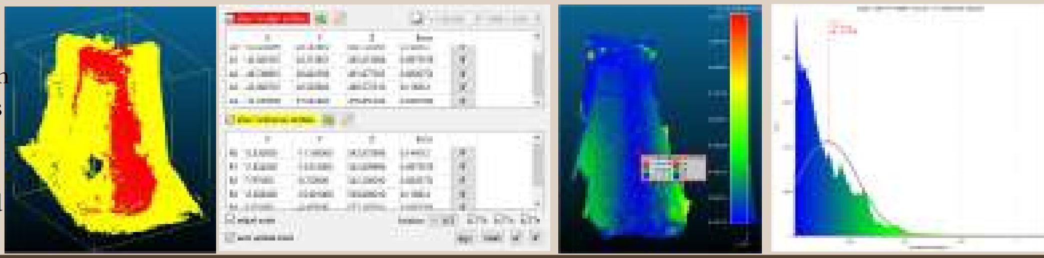


Survey A	
Date	05.07.2022
Time	10.00-12.00
Points n.	9,121,459
Frame n.	1205
Frame size	3000x4000
Height of fly	50 m
Survey B	
Date	14.04.2023
Time	09.00-11.00
Points n.	10,320,105
Frame n.	1256
Frame size	3000x4000
Height of fly	50 m

Reliability of SfM survey and Precision

Alignment

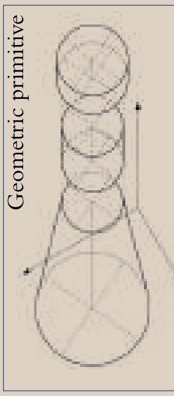
Process by which relative positions and orientations of multiple datasets acquired are determined.



Precision

Difference between measured coordinates and actual coordinates in the global reference system.

Definition and construction of the models: Theoretical model and Empirical models



Elliptical Cylinder
a'' 11,31m
b'' 11,26m
h'' 2,90m
Elliptical cylinder
a' 9,66m
b' 9,70m
h' 5,70m
Truncated Elliptical Cone
a 18,08m
b 18,21m
h 17,02m

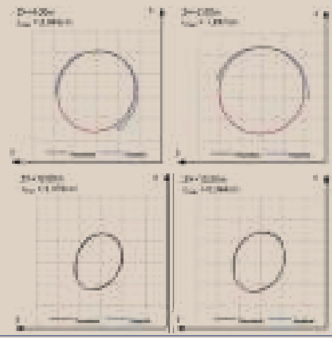
Geometric solid model

Theoretical model

Contour plot model
Photogrammetric model

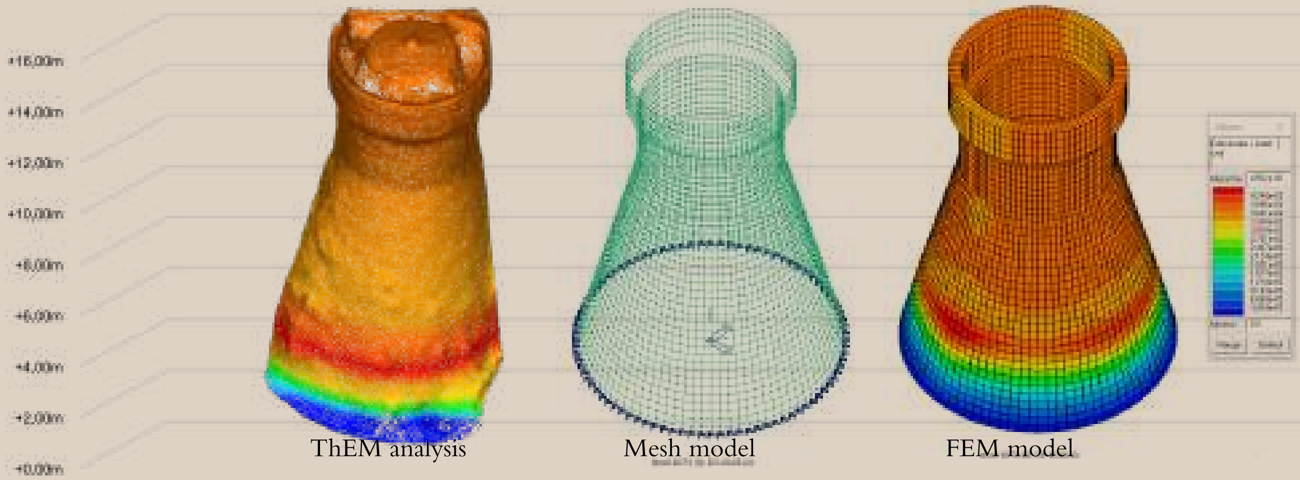
Empirical model

Comparison between the models and results



The tower's geometry is derived from the synthesis of solids, culminating in an idealized theoretical volume. An empirical model of the tower can be generated using mesh surfacing obtained from a digital point cloud. These two models enable the extraction of transversal and longitudinal sections. Examination of the tower's structure involves the extraction of cross sections at intervals mirroring the dimension of its stones. Discrepancies in distance and surface deformation between the theoretical and empirical models are scrutinized through a process of superimposition. Displacement data for each section are analyzed and segmented. The resultant output is depicted on a color-coded graphical representation, with regions of maximal deformation highlighted in red.

Validation of the procedure



Reference: Pelliccio, A., Saccucci, M., & **Miele, V.** (2023). Deformations of the Fortress Towers Analyzed by the SfM Survey. Nexus Network Journal, 25(Suppl 1), 39-46.

VII

DISCUSSION

FINAL

REFLECTION

Conclusion Reccomendations

1. Validation of Hypotheses

The present research illustrates the outcome and the knowledge gained in deep investigation of the fortified architecture along the historical border between the Papal States and the Kingdom of Two Sicilies. In such a respect, this work has dealt with problems regarding the use of digital methodology and conservation effort in relation to historical research for deepening knowledge of such structures when very often historical records are not available. The research consequently applies an interdiscipline approach, besides archival research and highly sophisticated digital modeling techniques to bridge the gaps in historical knowledge with modern preservation strategy. The principal objectives are: filling in the lacuna in the historical record concerning one of the most important features of fortified architecture. It does so by combining data capture in a novel way, utilizing structured ontologies that set a comprehensive framework for both the historical and technical aspects of the architecture. This yield a far finer-grained understanding of medieval fortifications than previously possible, demonstrating how such methodologies might be used in other contexts extending beyond this particular geographical area covered in this study.

The outcome of this research consists in the development and testing of complex ontological-structure-based HBIM parametric models with more knowledge of fortified architecture and its historical evolution. The outcome of such a perspective opens new views on scholarly research and public engagement with cultural heritage, principally by making digital models accessible via the web. Conclusions draw on the wider applicability of the general procedure FORTdigiTALE as a general methodology for studies on fortified architecture in different geographical areas and historical periods. Thanks to the universal approach, this makes the resultant output of the research easily exportable to other fortifications to support homogeneous analyses and conservation strategies. The data obtained with this methodology can be profitably used within education and promotional projects to bring out the importance of digital technologies for knowledge preservation and sharing related to cultural heritage. This research confirms the integrated, interdisciplinary approach necessary in the study of fortified architecture and adds new knowledge on fortifications in Southern Lazio by setting the bases for further research on conservation of these architectural heritage in Italy and abroad.

To substantiate the thesis hypothesis, a detailed discussion is required that thoroughly addresses the research questions.

1. How can historical analysis be conducted to conserve fortified architecture, especially when documents, particularly from medieval areas, are scarce?

This thesis demonstrates that lack in historical sources for fortified architecture in regions like Southern Latium can still be effectively helped through a combination of digital surveying techniques, historical hypothesis reconstruction, and the integration of geographical data(GIS). When historical documents are limited or incomplete, as is often the case with medieval structures, the use of Structure from Motion (SfM) techniques provides essential data about the physical condition and dimensions of these structures. These tools allow for detailed 3D reconstructions of sites, which, when cross-referenced with any available documentation, yield a more complete understanding of the original architecture. The analysis also shows that drone-based photogrammetry, combined with HBIM helps compensate for the lack of documentary sources by offering a non-invasive method to gather data from difficult-to-access sites. These technologies also allow the mapping of structural deformations, thus contributing to a better understanding of the building's material evolution. Thus, even when historical documents are scarce, digital methodologies and integrated modeling systems provide an effective alternative for the conservation and understanding of fortified architecture. The work demonstrates how combining technology with historical data available can lead to a more precise, hypothesis-based restoration approach that respects the historical integrity of the fortifications.

2. How can the construction of informative modeling integrated with structured ontology enhance knowledge about fortifications?

The construction of informative modeling integrated with structured ontology enhances knowledge about fortifications by creating a detailed and systematic representation of the architectural and historical data. Through HBIM, combined with ontology-based semantic databases, it is possible to organize not only the geometric and material data of fortifications but also integrate historical, environmental, and structural information. This modeling approach enables a better interdisciplinary understanding of the fortifications, making it easier to analyze the connections between their construction techniques, historical developments, and current conditions. The use of parametric modeling and structured ontologies also makes it possible to compare different sites, observe typological similarities, and manage restoration interventions more systematically.

By integrating informative modeling and structured ontology, knowledge about fortifications is enhanced, leading to a more comprehensive understanding of these structures in terms of their architectural evolution, material conditions, and historical context. The structured ontology helps unify fragmented data, making it more accessible for both scholars and conservationists.

3. What is the level of awareness regarding the conditions of neglected fortifications?

Many fortifications, especially in Southern Latium, suffer from neglect and degradation, with minimal awareness of their current structural conditions. Through the analysis conducted using GIS and photogrammetry, the work exposes the extent of deformation and material degradation in these structures. While some regions and institutions have engaged in restoration efforts, much of the awareness of the fortifications' condition is limited to local communities, and many structures remain abandoned or poorly maintained.

The integration of digital surveys and the dissemination of these findings through educational and popularization channels could potentially raise awareness and lead to better conservation strategies. However, the current level of awareness remains relatively low, especially considering the historical significance of these sites. The level of awareness regarding the conditions of neglected fortifications is limited, and while this research brings to light the structural and material problems, greater efforts are needed to popularize and educate the public and policymakers on the urgency of preservation and restoration.

4. Does the presence of two distinct states, the Papal State and the Kingdom of the Two Sicilies, in Southern Latium create differentiation in fortifications? And In what ways do technologies and environmental or political factors influence fortification construction and arrangement?

The presence of two distinct states did create differentiation in the construction and purpose of fortifications. Geopolitical and cultural factors influenced their design, distribution, and functional role, reflecting the specific needs and priorities of the Papal State and the Kingdom of the Two Sicilies. The study illustrates how technological advancements, such as the introduction of gunpowder and artillery, significantly influenced the arrangement and construction of fortifications, particularly in the later stages of their development. These technologies necessitated the creation of thicker walls, bastions, and more complex defensive systems capable of withstanding sieges. Furthermore, environmental factors like the topography of the region also played a critical role, as many fortifications were placed on elevated terrains for strategic defense. The presence of rivers, hills, and valleys dictated the arrangement and shape of the fortifications, as shown in GIS database. On the political side, fortifications were directly influenced by the shifting alliances, wars, and border conflicts between states, as discussed in the analysis of the Liri Valley fortifications.

Technological advancements, particularly in military technology, as well as environmental and political factors, played a crucial role in influencing the construction and arrangement of fortifications. These influences are visible in the design choices that adapted to new threats and geopolitical landscapes.

6. Can a universal method be developed for studying other fortification cases, and how can the collected data be used for promotional and educational purposes?

The thesis proposes a universal methodology that combines historical analysis, digital surveying, and informative modeling to study fortified structures. This method, which integrates HBIM, GIS, and Scan to BIM techiques is applicable beyond the specific case of Southern Latium, offering a framework that could be used to study fortifications globally. Further inquires can highlight the importance of using the collected data for educational purposes. The creation of digital models, interactive maps, and virtual reconstructions offers opportunities for popularization and educational outreach, making these sites accessible to a broader audience, including schools, tourists, and researchers. So, the methodology developed in this thesis can serve as a universal approach for studying other fortification cases. The integration of digital tools and ontological frameworks not only aids research but also provides valuable opportunities for promotional and educational initiatives, enhancing public engagement with historical heritage.

2. Achievement of research objectives

The current thesis tries to address the chronic methodological problems in studying and conserving fortified architectural heritage in Southern Lazio, a region where the scarcity of archival resources and the limited archaeological investigations have long been recognized since the beginning of the 20th century. Indeed, these issues have changed little today and really present serious problems in the comprehensive research and conservation process. This research therefore attempted a combined methodology that effectively integrates scattered data by applying state-of-the-art digital tools, in particular BIM and HBIM, along with structured ontologies, notwithstanding the presence of challenges.

It has become ever so clear that the inclusion of digital methodologies has succeeded brilliangly in solving the lacunars left by fragmented historical documentation. HBIM allows the capturing of detailed multidimensional models of fortified architecture, combined in one digital framework along with historical, architectural, and technical information. These models, once enriched with links not only to archival documents but also to material descriptions, surely can be an asset for experts, who will then be able to operate with full awareness and precision in the analysis and conservation of these structures. On the other hand, integration among digital photogrammetry, laser scanning, and geoinformation systems went ahead to bring about high-resolution models in the pursuance necessary for appreciating architectural details apart from relating them with the intervening landscape. The most important outcome of this research was a systemized and accessible database which united previously fragmented data. The great potential of BIM in storing and interlinking many different types of information, from 3-D models to texts on history, creates an extensive tool for scholars and practitioners in work related to fortified architecture.

Such an operational tool could play a very important role in extending beyond the case studies of Southern Lazio but also being generally replicable for other regions in Europe with similar methodological and resource problems. Besides these specialists, the tool will be used to sensitize and engage the general public in issues pertaining to cultural heritage. Putting the digital models online makes the architectural heritage, usually ignored, more comprehensible and accessible to the general public. This democratisation of heritage information plays an important role in making people aware and also take an interest in investing in the conservation of neglected fortifications.

The initial hypotheses of the research have been validated through the results obtained. It was hypothesized that digital tools could significantly enhance the study and conservation of fortifications, especially in contexts where historical documentation is limited. The combination of digital technologies allowed for the reconstruction of architectural features, detection of material deformations, and structural analysis of fortifications, even in cases where the historical records were incomplete. The accuracy provided by these tools enabled a more informed approach to conservation.

3. Practical applications

The research shows that the combination of digital tools and historical methodologies offers a versatile approach applicable to various types of architectural heritage. The structured ontology developed in this research can be adapted to different architectural contexts, providing a scalable system for managing historical and material data. This framework fosters interdisciplinary collaboration between historians, architects, conservationists, and digital technologists, ensuring a comprehensive understanding of heritage sites. This universal applicability extends beyond Southern Latium, offering a methodological template for analyzing and conserving other types of historical architecture globally. The potential to standardize such an approach for diverse fortifications and heritage sites further demonstrates the value of the method developed in this thesis.

3.1 Popularization and educational aspects

The educational potential of the digital models developed in this research is significant. The creation of interactive 3D models, GIS maps, and virtual reconstructions offers a dynamic tool for engaging the public and promoting heritage awareness. The thesis emphasizes the importance of public engagement in heritage conservation, proposing that digital tools can serve as a means of popularizing historical knowledge. By making the research and conservation process more transparent and accessible, these tools can help foster a deeper appreciation of cultural heritage among local communities, students, and tourists alike.

4. Final considerations

In conclusion, this thesis provides a comprehensive methodological framework for the study and conservation of fortified architectural heritage. It demonstrates the effectiveness of digital tools in addressing both historical and conservation challenges, particularly in contexts where traditional documentation is limited. The research contributes to the ongoing dialogue between historical scholarship and technological innovation, offering a model that can be applied locally and internationally. By combining scientific rigor with educational potential, this work has set the foundation for future research and practical applications in the field of architectural conservation. Moreover, the universal applicability of the method ensures its relevance for a wide range of heritage sites, making it a valuable tool for both current and future generations of conservationists.

The approach to integrating digital technologies—such as HBIM, GIS, and SfM—in the study and conservation of fortifications is highly effective, particularly within the context of Southern Latium. While these technologies are increasingly used in heritage studies, this specific combination and methodological framework tailored to fortified architecture represent a valuable tool to foster knowledge on the topic and provide a decision making tool for the enhancement of this particular architectural heritage. The choice of case studies, especially focusing on the fortifications along the border between the Papal State and the Kingdom of the Two Sicilies, brings a novel geopolitical and architectural perspective. This borderland context, along with the comparative analysis of fortifications shaped by different political powers, brings depth and great research possibilities and further exploration for future developments.

The development of a universal framework for fortification analysis and preservation, extend the potential impact of the work beyond just a theoretical study. By focusing on both academic research and practical conservation applications, the work is balanced out in its versatility and potential contribution. The educational and popularization aspects can be implemented by focusing on the organization of a web platform dedicated to the study. Overall, the research tries to strike a balance between cutting-edge technological methods, historical analysis, and practical applications.

Advantages of the procedure

- Accuracy in Documentation: The use of photogrammetry, laser scanning, and Structure from Motion (SfM) technologies allows for extremely accurate and detailed documentation of architectural heritage, especially fortifications. This precision is crucial for analyzing structural conditions, identifying deformations, and planning interventions.

- Non-Invasive Methods: The digital techniques employed, particularly drone photogrammetry, provide a non-invasive approach to surveying heritage sites. This is particularly beneficial for fragile or hard-to-reach fortifications where traditional methods might risk further damage.

- Comprehensive data integration: The use of HBIM and GIS enables the integration of a wide variety of data, including geometrical, historical, and material information. This creates a more holistic understanding of each site, allowing for better-informed conservation strategies.

- Universal Applicability: The methodological framework can be applied to various types of heritage sites, beyond the specific case of Southern Latium. The use of ontology-based databases allows for scalable application, making this a versatile tool for studying and conserving different types of architectural heritage.

- Preventive Conservation: The ability to detect deformations and monitor the structural integrity of fortifications through 3D modeling and digital surveys offers a proactive approach to preventive conservation, identifying potential problems before they become critical.

- Promotion of Educational and Public Engagement: By creating 3D models, virtual reconstructions, and interactive maps, the procedure not only aids researchers and conservationists but also serves as a powerful tool for educating the public and raising awareness about the importance of preserving heritage.

Possible drawbacks of the procedure

- Data Complexity and Management: The vast amount of data generated by these digital surveys and modeling techniques can be difficult to manage. This requires a well-structured data management system and personnel trained in handling complex datasets, which can be a bottleneck in smaller or less technically equipped conservation teams.

- Limited Historical Context: While the procedure excels in geometrical and material documentation, it is still dependent on available historical records to provide a complete picture. In cases where historical documents are limited, the digital models may be highly accurate structurally but lack historical context, making hypothesis-driven reconstructions necessary.

5. Recommendations for the field of conservation

- Adopt digital tools for documentation and analysis: The integration of digital technologies such as drone photogrammetry, Structure from Motion (SfM), and Historic Building Information Modeling (HBIM) should become standard practice in the documentation and analysis of architectural heritage. These tools offer precise, non-invasive methods for capturing structural details, monitoring deformations, and generating accurate 3D models, even in challenging or inaccessible locations. Their use can significantly enhance the understanding and preservation of complex fortifications and other heritage sites.

- Promote interdisciplinary collaboration: The field of conservation should foster stronger interdisciplinary collaboration among expertises. This approach ensures that both historical accuracy and modern technological advancements are applied in tandem, resulting in more informed and effective conservation practices. The integration of structured ontologies and semantic databases can bridge these disciplines, allowing for a more comprehensive understanding of heritage sites.

- Prioritize preventive conservation: Preventive conservation should be emphasized, particularly in regions prone to natural risks such as seismic activity. The use of digital deformation analysis and structural assessments, as demonstrated in this research, can help identify vulnerabilities in heritage structures before significant damage occurs. Regular monitoring using these digital tools will enable conservationists to take timely actions, mitigating the risk of irreversible loss.

- Raise public awareness and involve local communities: Public engagement is essential for the long-term success of conservation efforts. Digital models, virtual reconstructions, and interactive maps can be powerful tools for increasing public interest and awareness about heritage sites. Conservation projects should also actively involve local communities, using educational programs and digital platforms to make heritage preservation more accessible and relevant to a broader audience.

Implement scalable and universal conservation methodologies: The digital framework developed in this research, which combines Scan To BIM, GIS, HBIM, and structured ontology-based systems, can serve as a model applicable to various types of heritage sites. Conservation authorities and practitioners should consider adopting such methodologies as they offer scalable solutions for managing and preserving diverse architectural forms, from local fortifications to global heritage monuments.

- Ensure documentation transparency and accuracy: In any digital or physical restoration, it is critical to maintain transparency in documentation. All data collected, whether through photogrammetry or archival research, should be clearly categorized based on its reliability and historical certainty.

- Encourage the development of educational resources: Conservation efforts should prioritize the creation of educational resources that not only preserve historical knowledge but also disseminate it widely.

Concluding, this research provides a link between the knowledge of the past and present needs related to preservation, with a valid and easily scalable methodology for the study of fortified architecture. This thesis significantly contributes to both scientific research and heritage conservation, guaranteeing that these historical buildings are documented, studied, and preserved for the future; by overcoming certain methodological limitations that have implicated research up to now, and by providing an operational tool adaptable to other European contexts.

VIII

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Fig. 16 The graphic elaboration of the Angevin castle layout shows the rooms' location intended for prisoners. (Elaboration by the author)

Fig. 17 Bourbon cells. Narrow hallway and the stone beds and pillows. (Author's photos)

Fig.18 Piedmontese cells. The wooden doors in the original color, numerous writings that identify the intended use of the rooms are still preserved. (Author's photos)