



Università
di Catania



DICAR
Dipartimento di
Ingegneria Civile
e Architettura

UNIVERSITY OF CATANIA

Department of Civil Engineering and Architecture

Doctoral Program in
Defense against Natural Risks and Ecological
Transition of Built Environment

XXXVIII cycle

Integrated Investigation and
Documentation Methodologies
for the Protection and Safeguarding
of Masonry Towers with
Ceramic Roof Coverings

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Abstract

The present doctoral research addresses masonry towers with ceramic coverings in Sicily, with particular reference to spires constructed using wedge-shaped glazed bricks. These architectural elements represent a significant yet still underexplored component of cultural heritage, characterised by distinctive constructive, material, and decorative features. Despite their historical and architectural value, these monuments have received only limited documentation, and are frequently subject to processes of decay and loss. The research therefore adopts an integrated and multiscalar approach aimed at improving their documentation, understanding, and conservation, relating the architectural scale of the individual artefact to the territorial dimension of production systems, raw material supply, and patterns of diffusion.

The research develops a methodological framework combining architectural survey, cataloguing practices, digital modelling, relational database design, and Geographic Information Systems (GIS) in order to structure, manage, and analyse heterogeneous datasets. This text focuses on the definition of a relational database that has been normalised and which has been implemented in PostgreSQL/PostGIS. The database has been designed to encode the relationships between towers, spires, production centres, quarries and municipalities. The database has been integrated within a Geographic Information System (GIS) environment (QGIS), thus enabling spatial queries and territorial analyses, including proximity assessments and distance-based evaluations. The latter are aimed at identifying potential production centres for artefacts lacking documented attribution.

At the architectural scale, an integrated survey protocol has been defined and applied to a selected set of case studies located in the province of Catania. These include the towers of the Cathedral of Acireale, the Basilica of Santa Caterina in Pedara, the Church of Santa Maria delle Grazie in Tremestieri Etneo, and the Church of San Pietro in Adrano. The survey combines Terrestrial Laser Scanning (TLS), Mobile Laser Scanning (MLS), and Structure-from-Motion (SfM) photogrammetry, ensuring the acquisition of accurate and comprehensive geometric data. The resulting point clouds facilitate the generation of two-dimensional drawings, three-dimensional models, and simplified geometries for structural analysis. The integration of survey-derived models and finite element modelling is explored as a tool for improving understanding of structural behaviour and supporting conservation strategies.

The documentation of the analysed towers is supported by the development of a cataloguing record structured in accordance with the standards of the Istituto Centrale per il Catalogo e la Documentazione (ICCD), within the framework of a broader collaboration aimed at defining an ontological model dedicated to towers. The record is organised into thematic sections addressing identification, location, functional and relational aspects, as well as geometric, morphological, architectural, and material characteristics. This configuration is intended to guarantee the uniformity of data documentation and enable the subsequent comparison of case studies. As a complement to the methodological framework, a compendium of cataloguing forms was compiled for the analysed

towers. By way of example, the documentation of the south bell tower of the Cathedral of Acireale is presented herein.

The analysis of the Valencian dome of the Church of the Escuelas Pías in Valencia is introduced as a comparative reflection, and is considered as a different typology of ceramic covering. This case offers an opportunity to discuss survey approaches and conservation issues in relation to a distinct constructive tradition, without constituting a direct application of the proposed methodological framework.

The primary outcome of the research is the establishment of an integrated and transferable methodological model for the documentation, analysis, and interpretation of architectural heritage characterised by ceramic coverings. The research contributes to the development of advanced knowledge systems oriented towards the conservation and valorisation of cultural heritage by establishing connections between architectural, material, and territorial data, and by integrating cataloguing tools with digital survey and spatial information systems.

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List of Abbreviations

AG	Agrigento
CL	Caltanissetta
CRS	Coordinate Reference System
CT	Catania
DBMS	DataBase Management System
EN	Enna
EPSG	European Petroleum Survey Group
ETRS	European Terrestrial Reference System
FEM	Finite Element Model
GIS	Geographic Information Systems
GNSS	Global Navigation Satellite Systems
HBIM	Heritage Building Information Modeling
ICCD	Istituto Centrale per il Catalogo e la Documentazione
ISTAT	Istituto Nazionale di Statistica
LOD	Linked Open Data
ME	Messina
MLS	Mobile Laser Scanner
PA	Palermo
RDN	Rete Dinamica Nazionale
RG	Ragusa
SfM	Structure from Motion
SLAM	Simultaneous Localization and Mapping
SQL	Structured Query Language
TLS	Terrestrial Laser Scanner
UAV	Unmanned Aerial Vehicle
UTM	Universal Transverse Mercator



Preface

This research falls within the field of studies concerned with the protection and enhancement of historical and architectural heritage, which represents the identity of the communities inhabiting a given territory. Bell towers, imposing structures rising above the architectural complex of churches, have historically marked the passage of time and accompanied religious celebrations. As symbolic architectures, visible within both urban and natural skylines and capable of spreading the sound of bells across long distances, they have historically fulfilled the dual role of watchtowers and territorial identity markers. Their geometric and formal configuration – characterised by a considerable height in relation to both their planimetric footprint and the elevation of surrounding buildings – makes bell towers elements that can be distinguished from the surrounding context, monumental landmarks endowed with both material and symbolic value and serving as reference points for the observer, providing a clear and legible image of the territory.

In Sicily, a substantial heritage of bell towers survives whose spires are either clad with, or entirely constructed from, wedge-shaped majolica bricks. These spires function as crowning architectural elements characterised by different geometries that emphasise their visibility. Beyond their formal configuration, they are distinguished by their finishing techniques, featuring majolica decorations with geometric and polychrome patterns that produce a strong visual impact and contribute significantly to shaping the skyline of the towns and villages in which they stand. These structures can be identified as true landmarks within the landscape, often poorly documented and gradually forgotten by contemporary communities, which are frequently distant from actions aimed at safeguarding and protecting these symbolic elements.

The research aims to advance the knowledge and documentation of bell towers with majolica-clad spires through the census and classification within a GIS environment, where the relationships between towers, spires, ceramic production centres, quarries, and the historical and geographical context are examined and analysed. In this framework, the geographic information system is not conceived solely as an archival tool,

◀ Detail of the south spire of the Cathedral of Maria Ss. Annunziata in Acireale (CT).

but rather as an analytical device capable of revealing patterns of diffusion, production networks, and spatial connections, thereby contributing to the construction of an interpretative framework at the regional scale. Cataloguing according to the standards of the Istituto Centrale per il Catalogo e la Documentazione (ICCD) complements this approach, ensuring consistency with national heritage documentation standards.

Starting from an initial investigation at the territorial scale, which highlights both the quality and the quantity of towers in Sicily characterised by glazed ceramic spires, the research develops a critical investigation at both architectural and detail scale through digital survey activities. The study experiments with digital survey methodologies as tools for preserving historical memory, analysing form and geometry, and documenting construction techniques, decay phenomena, structural damage, transformations and stratifications, as well as any restoration and consolidation interventions. The material produced constitutes a digital archive that preserves, through the elaborated three-dimensional models, both the historical and contemporary condition of these structures. It represents an operational tool capable of supporting future intervention strategies, combining technological innovation with respect for the constructive memory of the buildings.

To date, the study conducted on bell towers spires has made it possible to identify one hundred and twenty-nine spires in Sicily featuring glazed ceramic elements in their roofing systems. Among these, eighty-five are characterised by elements known as wedge-shaped bricks (locally referred to as *bugnette* or *zoccoli*), while the remaining examples employ ceramic tiles or shingles (also called *squame* or *embrici*). These structures, in most cases dating between the seventeenth and eighteenth centuries, are mainly concentrated in municipalities located in inland areas and in zones close to the principal ceramic production centres: Burgio, Caltagirone, Santo Stefano di Camastra, Naso, Collesano, and Gangi. The earliest documentary evidence concerning the supply of wedge-shaped bricks for the construction of a spire in Sicily dates back to 1579 and refers to the Church of San Giacomo in Collesano. The most recent example can instead be associated with the Church of Borgo Giuliano, in the territory of San Teodoro (Messina), erected before 1940 and currently in a state of ruin, where the reinforced concrete spire of the bell tower and the semi-domes of the lateral chapels are clad with glazed wedge-shaped bricks produced in Santo Stefano di Camastra.

Spire roofing systems are subject to several factors of deterioration related both to the characteristics of the ceramic material – exposed to atmospheric agents and mechanical stresses – and to the specific features of the supporting structure. The laying system may facilitate water infiltration within the masonry fabric and the accumulation of loose material in projecting elements, leading to vegetation growth that progressively disintegrates mortar joints and bricks. Metallic elements located at the top (crosses and weathervanes) or embedded within the body of the spire (maintenance ladders and tie rods) constitute additional sources of deterioration: besides producing chromatic alterations, thermal expansion and contraction phenomena can generate cracks in the ceramic elements. In the event of seismic activity, moreover, the concentrated loads at the top of the structure significantly influence the global structural behaviour. For these reasons, it becomes necessary to investigate the tower–spire system as an integrated whole, consid-

ering both the external cladding and the load-bearing structure.

To this end, several preliminary numerical analyses were carried out on the towers, providing indications on the possible kinematic behaviour of the spires and allowing the distinction between seismic vulnerability conditions and forms of deterioration related to other causes.

The results of a preliminary investigation have also made it possible to identify several types of interventions carried out on spires characterised by this construction technology. In many cases, structural consolidation has been undertaken through the installation of metal hooping systems, accompanied by stitching operations using connectors and mortars, or through the application of structural meshes (Church of San Francesco, Ascoli Piceno)¹. In other cases, interventions have consisted of repointing the joints with hydraulic lime and sand mortars (Church of Santa Maria Annunciata, Gussola). In some instances, stabilisation measures have involved the construction of extrados wooden and copper coverings superimposed on the original structure (Cathedral of Parma)². Although this solution may ensure the conservation of the structure, it permanently conceals its appearance and may negatively affect structural equilibrium if not properly designed. Most of these interventions, while responding to structural requirements, have sometimes altered the formal and perceptual characteristics of the spires, not always considering the historical and aesthetic value of this heritage. The preliminary analysis highlights the absence of a shared methodological approach capable of integrating conservation, consolidation and enhancement strategies.

Furthermore, the research activity conducted at the Universitat Politècnica de València made it possible to further investigate ceramic roofing systems in the Valencian Community. This study aimed to identify similarities and differences with respect to the Sicilian context, highlighting the technical and formal specificities of the local tradition.

Against this background, the present research adopts a multidisciplinary approach aimed at developing an integrated framework of knowledge, territorial and architectural of ceramic spires in Sicily, with the objective of defining informed and replicable intervention criteria. The structure of the thesis, organised into theoretical, methodological and applied chapters, reflects this approach and progressively presents its tools, case studies and results.

Structure of the thesis

The thesis is organised into ten chapters, structured as a progression from the general theoretical and methodological framework to the definition of operational tools, and finally to their application to case studies and the assessment of the method's potential.

Following the Preface, which outlines the research topic and frames its motivations and context, Chapter 1 provides a general overview aimed at defining the main disciplinary fields involved and delineating the scope of the study.

Chapter 2 focuses on the theoretical-methodological framework and the state of the art, and is structured around four main thematic areas: the conservation and protection

1 <https://www.giancarlomariani.it/wp-2/project/chiesa-s-francesco-messa-in-sicurezza-cuspide/>

2 <https://www.impresedilineas.it/restauro-della-cuspide-e-ripristino-della-copertura-in-rame/>

of cultural heritage; the cataloguing of cultural heritage, addressed both from a theoretical-methodological perspective and through a review of national experiences; the representation and organisation of territorial data, with particular reference to cartographic principles, GIS systems and relational and spatial database models; and finally, digital architectural surveying, analysed in its methodological principles and recent developments, with specific attention to the survey of towers.

Chapter 3 sets out the main research questions, in relation to which the corresponding research objectives are defined, outlining in a structured way the knowledge-based and operational aims guiding the entire study.

Chapter 4 defines the adopted methodology, clarifying the overall approach and the operational phases that structure the development of the research.

Chapters 5 and 6 provide the reference knowledge framework on the topic of ceramic roof coverings. In particular, Chapter 5 examines the role of ceramics as both a constructive and decorative element, analysing their historical development, production cycle, application techniques in roofing systems, and the main deterioration phenomena. Chapter 6, in turn, focuses on two geographical and cultural contexts – Sicily and the Valencian region – analysing their respective construction traditions related to ceramic roof coverings, with reference to historical and production aspects, territorial distribution, architectural characteristics, landscape value and conservation conditions.

Chapter 7 introduces the territorial information model developed for documenting towers with ceramic roof coverings, describing the translation of the conceptual model into a relational structure and its integration within a GIS environment. This chapter therefore defines the architecture of the information system that enables the integration of architectural, production and territorial data.

Chapter 8 focuses on architectural documentation and the analysis of case studies, representing the main application phase of the research. After defining the criteria for case selection, the integrated survey protocol is presented, together with the results of the acquisition and documentation processes for the analysed towers. The chapter also includes a comparison between the different surveys, the definition of the cataloguing record, and the integration of geometric models with structural analyses, highlighting the potential of the adopted approach from both a knowledge-based and diagnostic perspective.

Chapter 9 examines the case of the dome of the Escuelas Pías in Valencia as an opportunity to reflect on the adopted survey protocol. The case study is analysed with reference to the phases of data acquisition and documentation in support of knowledge development prior to restoration. Attention is therefore paid to the critical evaluation of procedures and results, in order to highlight specific aspects related to the different architectural typology and to identify elements useful for assessing and potentially adapting the protocol developed for Sicilian spires.

Finally, Chapter 10 presents the conclusions of the research, summarising the main results, highlighting the limitations of the study, and outlining possible future developments.



Chapter 1 - Introduction

Architectural heritage constitutes a layered and articulated reality in which material, historical, cultural and territorial relationships are deeply intertwined. Each building is embedded within a network of connections involving the urban and landscape context, construction techniques, local resources, production dynamics and the transformations that have occurred over time. Its understanding therefore requires an interpretative approach capable of integrating multiple dimensions, moving beyond an exclusively formal or stylistic reading and encompassing the analysis of construction systems, the physical properties of materials, and the environmental conditions to which the building is subjected.

Within this perspective, cultural heritage does not merely represent a testimony of the past, but an active resource for contemporary communities. It contributes to the construction of collective identity, to the quality of urban and rural landscapes, and to the cultural and economic development of territories. Its protection and enhancement, however, cannot be separated from in-depth knowledge capable of capturing its relational dimension, constructive structure and conservation conditions, thus avoiding reductive interpretations that may compromise its understanding.

Historic architecture can in fact be understood as the outcome of evolutionary processes that bring together materiality, function and meaning. The material dimension – understood as the set of techniques, materials and structural systems – constantly interacts with the intangible dimension, which includes identity values, collective perception and recognisability within the landscape. The long-term behaviour of a building is determined by the interaction between form, geometry, structural configuration and external actions, as well as by the quality of execution and maintenance; understanding these dynamics constitutes an essential premise for guiding informed conservation choices.

Such complexity calls for a clearly articulated multiscale approach, in which the different levels of analysis – territorial, urban, architectural, constructive and material – are conceived as interconnected layers within a unified interpretative framework. The

territorial scale enables an understanding of relationships between buildings, resources and production networks; the urban scale highlights their morphological and perceptual role; the building scale enables the analysis of their structural organisation; and the constructive and material detail makes it possible to investigate techniques, decay phenomena and mechanical behaviour. Each level contributes to the definition of the overall identity of the asset and shapes its processes of conservation and transformation.

Within this context, vertical structures assume particular significance, as they make evident the relationship between the building and the landscape. Towers, bell towers and domes emerge from the built fabric, acting as visual landmarks and recognisable elements within the morphology of the territory. Their verticality amplifies their presence in both the urban and natural skyline, endowing these structures with meaning that extends beyond their strictly functional role.

However, this prominence implies a twofold vulnerability. Direct exposure to weathering agents accelerates material decay processes, particularly in the upper parts; at the same time, the slender configuration and vertical distribution of masses make these structures sensitive to dynamic actions such as wind and seismic events, as well as to potential settlements of the foundation ground. They therefore fully belong to at-risk cultural heritage, understood not only as a set of assets threatened by catastrophic events, but as a fragile system subject to progressive and sometimes irreversible transformations. The absence of monitoring, planned maintenance and coordinated conservation strategies can, over time, compromise both the material integrity and the symbolic value of these structures.

Despite the breadth of studies dedicated to architectural heritage, knowledge of these phenomena is often structured along separate disciplinary lines. Art-historical research tends to privilege formal and documentary analysis; technological and structural studies focus on static behaviour and failure mechanisms; cataloguing activities organise data within descriptive frameworks that rarely engage with territorial analysis tools or structural interpretative models. While each of these approaches produces significant contributions, this fragmentation ultimately limits the possibility of providing a unified understanding of the building, which is essential for the development of coherent and informed conservation interventions.

In recent decades, digital transformation has provided new opportunities to overcome these discontinuities. Three-dimensional survey techniques enable the acquisition of highly accurate geometric data, documenting both formal configuration and crack patterns; geographic information systems allow for the organisation and analysis of spatial data at the territorial scale; numerical modelling makes it possible to simulate the mechanical behaviour of structures under different loading conditions. In this context, cultural heritage is increasingly moving into a digital dimension, in which three-dimensional representation, data structuring and system interoperability are not merely tools for documentation, but become integral components of knowledge production, monitoring and long-term management.

However, the potential of these tools can only be fully realised when they are conceived as elements of a coherent framework capable of integrating heterogeneous data and multiple scales. In particular, the understanding of buildings cannot be separated

from the territorial context in which they are embedded. Each building embodies a system of relationships involving material resources, craftsmanship, supply networks and economic and cultural dynamics rooted in a specific geographical context. Territorial-scale analysis enables the identification of connections between buildings, production centres and extraction sites, thus providing a broader understanding of construction processes and the dissemination of techniques.

Within the Mediterranean basin, this interplay between local production, technology and landscape is reflected in various construction practices, including ceramic roof coverings. Located in the upper parts of buildings, they act as mediating surfaces between the building and its context, contributing significantly to the definition of the urban skyline. Their configuration depends on the availability of raw materials and the presence of established craft traditions, resulting in highly distinctive architectural landscapes. At the same time, the composite nature of the system – resulting from the interaction between the load-bearing structure and the ceramic covering – increases its sensitivity to decay phenomena and to environmental and dynamic stresses, thus requiring specific attention from a conservation perspective.

The combination of identity value, production specificity and structural vulnerability makes ceramic coverings a particularly emblematic field to highlight the need for an integrated interpretative approach. Their analysis requires the integration of territorial scale, architectural configuration and material-structural behaviour, overcoming the traditional separation between disciplinary domains and placing knowledge at the core of conservation strategies.

The present research aims to contribute to the development of a knowledge framework for ceramic coverings in the Mediterranean area, with particular focus on vertical architectures featuring glazed ceramic elements. The objective is to investigate these artefacts through a perspective that integrates territory, architecture and the constructive element, combining inventory, cataloguing, digital survey and preliminary structural analysis to build a unified knowledge framework.

The comparison between different Mediterranean contexts is particularly significant, as it enables the testing of the transferability of the adopted approach and highlights similarities and specific features in the relationships between ceramic production, architecture and territory. The contribution of this research lies in the integration of different scales and tools, with the aim of supporting more informed conservation and protection strategies, consistent with the complex and relational nature of cultural heritage.



Chapter 2 - Theoretical and Methodological Framework and State of the Art

The complexity of the issues addressed in this research requires a preliminary examination of the current state of studies and of the main theoretical and methodological references across the different disciplinary fields involved. The study analyses ceramic roof coverings of towers by integrating themes such as heritage conservation, digital cataloguing tools, geographic information systems, and survey methodologies applied to complex architectures.

The state of the art outlined here does not aim to provide an exhaustive review of the extensive existing literature; rather, it seeks to identify the main orientations and the most significant lines of research that have contributed to shaping the theoretical and methodological framework of reference. Attention is devoted to studies on the protection and conservation of architectural heritage, to systems for data cataloguing and management, to the use of GIS (Geographic Information Systems) and spatial and relational databases for territorial analysis, as well as to survey methodologies applied to complex architectures.

This chapter aims to highlight both the contributions of the existing literature and the methodological gaps that make an integrated and multiscale approach necessary. The state of the art thus constitutes an essential theoretical and critical foundation for guiding the methodological choices and the objectives of the research project.

2.1 - Conservation and Protection of Cultural Heritage

Over the course of the twentieth century, the concept of cultural heritage conservation was progressively consolidated through a series of international documents that defined its principles, aims and fields of application. A key reference is represented by the *Venice Charter* (1964), which established shared criteria for the conservation and restoration of monuments, affirming the principle of safeguarding authenticity and transmitting heritage to future generations while respecting its historical stratification (ICOMOS, 1964). Since then, the discipline has undergone an evolution that has broadened

◀ Detail of the dome of the Iglesia del Temple, Valencia.

its focus from the individual monument to the urban and landscape context, recognising heritage as a complex expression of cultural, historical and identity-related values.

Within this perspective, the *Nara Document on authenticity* (1994) further developed the concept of authenticity in relation to cultural diversity, emphasising that heritage assessment criteria must consider the historical and cultural specificities of different geographical contexts (ICOMOS, 1994). These orientations have contributed to overcoming strictly formal approaches to conservation, promoting a perspective more responsive to both the cultural and material dimensions of heritage and to the plurality of meanings it assumes over time.

In parallel, the role of international organisations such as UNESCO (United Nations Educational, Scientific and Cultural Organization), ICOMOS (International Council on Monuments and Sites) and ICCROM (International Centre for the Study of the Preservation and Restoration of Cultural Property) has strengthened the regulatory and operational framework for heritage protection. The 1972 *Convention concerning the Protection of the World Cultural and Natural Heritage* (UNESCO, 1972) recognised the universal value of certain cultural and natural sites, promoting forms of cooperation among States for their safeguarding and consolidating the idea of heritage as a collective asset of humanity. ICOMOS has played a central role in the development of sector-specific charters and guidelines, while ICCROM has contributed to the advancement of training and research programmes in the field of conservation.

At the European level, the *Convention for the Protection of the Architectural Heritage of Europe* (Council of Europe, 1985), known as the *Granada Convention*, reaffirmed the central role of architectural heritage as a structuring element of the European cultural landscape. Similarly, the *Framework Convention on the Value of Cultural Heritage for Society* (Council of Europe, 2005), known as the *Faro Convention*, emphasised the role of heritage in shaping identity, fostering democratic participation and promoting the shared responsibility of communities.

More recent approaches in the management of cultural sites are reflected in the manual *Managing Cultural World Heritage* (UNESCO, 2013), which highlights the importance of integrated strategies based on planning, monitoring and coordination among the various stakeholders involved. In this context, protection is no longer conceived as an episodic intervention, but as a continuous practice requiring analytical, documentation and control tools suited to the complexity of contemporary heritage.

At the national level, the principles developed at the international level are implemented through regulatory instruments and operational strategies aimed at safeguarding cultural heritage. In Italy, the *Decreto legislativo 22 gennaio 2004, n. 42. Codice dei beni culturali e del paesaggio* (D.Lgs. 42/2004) represents the main reference for the protection, conservation and enhancement of cultural heritage, defining it as a public good and recognising its historical, artistic and identity value, while assigning a central role to knowledge and documentation within the protection process. Conservation is thus understood as a permanent institutional responsibility, involving systematic activities of study, monitoring and management.

In this context, heritage protection is embedded within a broader framework of policies oriented towards sustainable development. In September 2015, the international

community adopted the 2030 Agenda for Sustainable Development, increasingly recognising culture as both a driver of economic and social benefits and an enabler capable of enhancing the effectiveness of development policies (United Nations, 2015). Heritage conservation thus contributes to the development of sustainable communities, in which economic, cultural and social dimensions are closely interconnected.

Within this growing focus on the sustainability and the resilience of spatial systems, recent decades have also seen increasing attention to the issue of risk as applied to cultural heritage. Natural hazards, environmental degradation, structural vulnerability and lack of maintenance have highlighted the widespread fragility of the historic built environment, shifting conservation policies towards preventive strategies rather than purely emergency-based responses. Documents such as *Managing Disaster Risks for World Heritage* (UNESCO, 2010) and the *Sendai Framework for Disaster Risk Reduction 2015–2030* (UNDRR, 2015) have emphasised the importance of integrating risk management into ordinary conservation processes, promoting approaches based on prevention, planning and resilience.

At the technical and scientific level, the *Principles for the Analysis, Conservation and Structural Restoration of Architectural Heritage* (ICOMOS, 2003) highlight that any intervention on historic buildings must be grounded in a thorough understanding of structural behaviour and failure mechanisms, recognising the central role of diagnostic investigations and structural analyses within the conservation process. In Italy, this approach is translated into practice through the *Linee guida per la valutazione e riduzione del rischio sismico del patrimonio culturale* (Presidenza del Consiglio dei Ministri, 2011), which define methodological criteria for vulnerability assessment and for the design of interventions compatible with the constructive characteristics of historic buildings. In this context, risk assessment is not limited to the probabilistic estimation of damage but implies an in-depth understanding of the structural behaviour of the building.

Studies on the seismic vulnerability of historic buildings have further highlighted the need to combine qualitative and quantitative approaches in risk assessment, integrating the analysis of local collapse mechanisms with numerical models capable of capturing the global behaviour of masonry structures (Lagomarsino & Podestà, 2004; Lourenço, 2006). In parallel, international literature has also emphasised the importance of integrating the structural dimension with broader strategies of disaster risk management and cultural heritage resilience (Jigyasu, 2013), highlighting the importance of systemic knowledge as a prerequisite for any conservation strategy.

Conservation can therefore be understood as a continuous process of interpretation, management and prevention, in which theoretical principles, technical tools and institutional responsibilities converge within a coherent framework. Since protection is grounded in knowledge, it becomes essential to adopt tools that can collect, organise and ensure the interoperability of data related to cultural heritage, transforming it from an object of episodic intervention into a structured system of data supporting management and risk prevention.

2.2 - Cataloguing of Cultural Heritage

2.2.1 - Theoretical and Methodological Framework

Cataloguing represents one of the fundamental tools for the knowledge, protection and management of cultural heritage. It consists of the systematic process of collecting, organising and structuring information relating to cultural heritage, aimed at documenting its characteristics, state of conservation, historical context and territorial relationships. Cataloguing is therefore not limited to a simple description of the asset, but constitutes a structured knowledge framework, based on shared methodological criteria and standardised classification systems. Through the definition of descriptive models, controlled vocabularies and data recording procedures, cataloguing makes it possible to ensure that information is comparable, interoperable and reusable over time. Within this perspective, the catalogue can be understood as an information infrastructure that is essential for research, planning and heritage protection activities.

2.2.2 - State of the Art of Cataloguing in Italy

The cataloguing of cultural heritage in Italy is governed by the *Codice dei Beni Culturali e del Paesaggio* (D.Lgs. 42/2004 and subsequent amendments), in particular by Article 17, which defines the procedures for establishing, expanding and updating the national catalogue of cultural heritage. Within this regulatory framework, the Istituto Centrale per il Catalogo e la Documentazione (ICCD), established in 1975 by the Ministry of Culture, manages the General Catalogue of Cultural Heritage, overseeing the unification, development and dissemination of cataloguing standards (Mancinelli, 2018) – including criteria for data acquisition, management and preservation, as well as controlled vocabularies – and administering the *Sistema Informativo Generale del Catalogo* (SIGECweb), a web-based platform that governs the entire cataloguing workflow.

In the traditional system, cataloguing is based on a structured framework composed of a schema and a set of compilation guidelines: the schema defines the hierarchical structure of fields and the formal constraints of the cataloguing record, while the guidelines provide operational and semantic instructions for data entry (Caruso, 2025). Despite the robustness of this system and the large amount of information produced over time, it has revealed critical issues related to descriptive inconsistencies and the fragmented cataloguing campaigns, with consequences for overall readability, data reusability and the possibility of achieving a relational representation of heritage at the national scale (Veninata, 2025). These limitations have shown that cataloguing, if not adequately structured and updated, risks being reduced to a purely descriptive exercise, not always capable of effectively supporting the needs of protection, management and territorial analysis.

In particular, the cataloguing of architectural and landscape heritage is conducted through the Scheda A – Architettura of the Catalogue, which, especially in situations of extreme emergency, has revealed limitations in effectively supporting the knowledge and safeguarding of cultural heritage. These critical issues are mainly due to the lack of

consistency in past cataloguing campaigns and to the intrinsic complexity of the schema, which has proved difficult for compilers to use, particularly in the absence of adequate terminological resources and due to the inability of existing cataloguing tools to account for the specific characteristics of each architectural asset.

For these reasons, since 2017, ICCD has initiated a process of renewal of the Catalogue, drawing on recent developments in the fields of Digital Humanities and Digital Cultural Heritage. Within this perspective, the ArCo ontology network (Architettura della Conoscenza)¹ plays a key role, aiming to make catalogue data more coherent, reusable and, above all, more easily connected to other information systems. In this context, an ontology can be understood as a formal conceptual model that describes the main concepts of a domain and the relationships between them; such a model makes it possible to overcome the idea of the individual record as a closed container, promoting a more relational and interoperable representation of heritage. On this basis, data can be published as Linked Open Data (LOD), that is, open data designed to be interconnected and queried across systems, ultimately forming a knowledge graph that links assets, places, actors, events and contexts (Caruso, 2025).

In parallel, the renewal of the National Catalogue has been realised through the development of the Sistema del Catalogo Nazionale – CLIO (Catalogazione, Localizzazione, Identificazione e Organizzazione). CLIO adopts a modular and incremental approach: descriptive models are no longer predefined monolithic schemas but are constructed during cataloguing through the assembly of information modules starting from a common mandatory core, to which general and specialised information is progressively added according to the project's knowledge objectives (Aras et al., 2025). Particular importance is assigned to the geographical and territorial dimension, as the platform integrates geolocation procedures and geo-editing tools, strengthening the relationship between cataloguing data and spatial context (Montalbano, 2025).

The ALOA project (Aggiornamento Lessici e Ontologie per l'Architettura)² forms part of this broader initiative of the Institute, and its working group includes architectural and conservation historians from various institutions and universities. The project aims to “develop an ontology-based system capable of managing and integrating the multiplicity and variety of data generated by different activities of analysis, study, restoration and maintenance of built heritage (historical research, material and diagnostic analyses, 2D and 3D survey, etc.)” (Metin & Rognoni, 2024). Its objectives include the creation of a user-friendly cataloguing tool and the improved access to catalogue information through a structured and efficient organisation, as well as increased data interoperability.

The first phase of the project involved the definition of the schema of the new Scheda A, alongside the development of the related architectural domain. The cataloguing tool developed is organised according to a logical and hierarchical sequence of structured fields, guiding the user from a general description to a more formalised and detailed

1 <http://www.iccd.beniculturali.it/it/percondividere/ProgettoArCo>

2 <https://iccd.cultura.gov.it/it/progetti/5386/progetto-aloa-aggiornamento-lessici-e-ontologie-per-l-architettura>

description of the artefact and all its components. The second phase, following the definition of the basic structure for the architectural domain, focused on the development of specific typological descriptive models, beginning with the model for buildings used for Christian worship. The section of the record dedicated to the identification data of the asset (codes, geographical-administrative and cadastral location, georeferencing and constraints) retains the same structure and vocabularies already in use within the catalogue, whereas the descriptive section has been completely redesigned. In the third phase, the tool was tested through its application to selected ecclesiastical buildings, including the Cathedral of Ascoli Piceno (Metin & Rognoni, 2024). It should be noted that the new cataloguing system, although developed in its conceptual and technological components, is not yet fully operational at the national level and is currently in a phase of implementation and testing.

Within this context, the present research also contributes to the ongoing activities of experimentation and modelling related to the architectural domain. In particular, the research has contributed to the development and validation of an ontological component related to towers, with the aim of making the description of this class of artefacts more structured and interoperable within the broader framework of the renewal of cataloguing standards.

In addition to the transformations outlined above, increasing attention has also been given to the diachronic dimension of cataloguing data. The possibility of tracing changes over time, terminological revisions and interpretative updates allows for the preservation of the knowledge stratification associated with cultural heritage, making explicit the very process of knowledge construction. Data are no longer understood as static records, but as dynamic elements, open to progressive integration and critical reinterpretation in line with the evolution of research and methodologies.

Within this framework, cataloguing is no longer merely a descriptive device but emerges as a strategic knowledge infrastructure for heritage protection. The quality, consistency and interoperability of data become essential requirements for the planning of interventions, the monitoring of conservation status and the preventive management of risk, particularly in complex territorial contexts. The relational and geographical structuring of information makes it possible to interpret heritage not as a collection of isolated entities, but as an integrated system of artefacts, contexts and relationships, thus laying the foundation for informed, multiscale and prevention-oriented conservation.

2.3 - Representation and Structuring of Territorial Data

2.3.1 - Theoretical and Methodological Framework

2.3.1.1 - Cartographic Foundations and Reference Systems

The use of GIS technology in the field of cultural heritage is rooted in the tradition of topography, understood as the discipline concerned with the representation, measurement and organisation of space through standardised and absolute reference systems. Cartographic representation constitutes an abstract representation of the territory, based on processes of selection, generalisation and symbolisation that translate the physical complexity of the earth's surface into a coherent and shared system of spatial relationships.

Among the fundamental elements of cartographic representation, scale, projection and the absolute reference system play a central role. While scale determines the level of detail (map scale) and the use of developable surfaces allows the projection of the earth's surface onto a plane, the reference system defines the mathematical framework within which positions are expressed through coordinates. In this context, it is essential to distinguish between geographic coordinates and projected coordinates. The former (latitude, longitude and ellipsoidal height), expressed in degrees, define the position of a point on the ellipsoidal surface of the Earth; the latter derive from the use of a developable surface and a cartographic projection and are expressed in metres on a Cartesian plane, typically as Easting and Northing coordinates, thus making them more suitable for metric analyses and direct measurements.

The adoption of a reference ellipsoid and an associated reference system (geodetic datum) establishes the origin and orientation of the geographic coordinate system used to model the Earth's surface. In the Italian context, official cartographic production has historically been based on the Roma40 datum, associated with the Gauss-Boaga conformal projection, structured into the West and East zones. This system, widely used in regional technical cartography and administrative documentation throughout the second half of the twentieth century, expresses coordinates in metres (planar cartographic coordinates), allowing direct measurement of distances on the projected plane. With the development of satellite technologies and GNSS (Global Navigation Satellite Systems), the use of the UTM (Universal Transverse Mercator) system has progressively become the standard. This system is based on a division of the Earth's surface into longitudinal zones of 6°. Italian territory falls within UTM zones 32N, 33N and 34N: the north-western area lies mainly in zone 32N, the central-eastern area in 33N, while the eastern and southern portions, including Sicily, are mainly within zone 33N, with limited extensions into 34N. As with the Gauss-Boaga system, UTM coordinates are expressed in metres using Cartesian Easting and Northing axes, facilitating measurement operations and spatial analysis in digital environments. Alongside the spread of the UTM system, more recent datums used in satellite positioning have also been adopted, such as WGS84 (World Geodetic System 1984) at the global level and ETRS89 (European Terrestrial Reference System 1989) at the European level. In Italy, the gradual transition from his-

torical systems based on Roma40 to those based on ETRS89 has led to the alignment of national cartographic datasets with international geodetic standards.

The correct management of geodetic reference systems is of particular importance in digital contexts, where the integration of datasets from different sources requires consistency between datum, projection and coordinate system. At the national level, these aspects have been clarified in the document *Nota per il corretto utilizzo dei sistemi geodetici di riferimento all'interno dei software GIS*, published by the Istituto Geografico Militare and updated in January 2022³, which provides operational guidelines for the correct definition and transformation of reference systems within GIS environments. With the transition to the digital domain, these principles are formalised in the so-called Coordinate Reference Systems (CRS), which can also be identified through EPSG codes, and which integrate datum, projection and coordinate system into a unified structure. Georeferencing makes it possible to associate each territorial entity with a specific CRS, transforming cartographic representation into a structured set of geometric objects endowed with measurable and comparable spatial positions. On these theoretical and technical foundations, Geographic Information Systems are developed, extending traditional cartographic logic by enabling the integration of geometric components with an organised system of descriptive attributes, thus transforming spatial representation into a queryable information infrastructure.

2.3.1.2 - Structure and Logic of GIS Technology

Building upon these foundations in geodesy and topography, GIS technology develops as more than a tool for digital cartographic representation; rather, it constitutes an integrated environment for the acquisition, organisation, analysis and visualisation of geographic data. Unlike traditional cartography, which provides a static image of the territory, GIS technology configures space as a structured information system in which each geographic entity is associated with a set of descriptive attributes that can be queried.

The fundamental structure of data in a GIS environment is based on the distinction between the geometric component and the associated data. In vector data structures, the digitisation of territorial elements is described through discrete entities represented exclusively by points, lines and polygons, each linked to an attribute table and assigned a unique identifier. This model is particularly suitable for representing well-defined and bounded objects – such as buildings, administrative boundaries, infrastructures and archaeological sites – and for analysing topological and metric relationships between entities. In the raster model, by contrast, space is divided into a regular grid of cells (pixels), each containing a numerical value representing a specific variable (elevation, temperature, land use, density, etc.). This structure is particularly suited to representing continuous phenomena and managing remotely sensed data or digital terrain models. The choice between vector and raster models is not merely a formal distinction, but entails different data storage, processing and analysis methods, influencing the types of

³ https://www.giseqgis.it/images/pdf_GEOMATICA/IGM-Gennaio-2022-nuova-nota-EPSG.pdf

queries and spatial operations that can be applied. The alphanumeric component, on the other hand, stores the descriptive information associated with each element, organised into tables linked to the geometry through unique identifiers. The integration of geometry and attributes makes it possible to move beyond simple cartographic visualisation, transforming the map into an interface for accessing a complex information system.

The organisation of geographic data is structured through thematic layers, each representing a specific category of information referenced to the same coordinate system. This layered structure makes it possible to decompose territorial complexity into homogeneous layers – such as settlements, infrastructures, administrative boundaries and architectural features – which can be visualised, overlaid and analysed in combination. The consistency of the reference system ensures the spatial alignment of different layers, enabling the integration of datasets from multiple sources.

One of the distinctive features of GIS technology compared to traditional cartography lies in the ability to query data both in attribute terms and, in the case of raster data, in terms of pixel values, as well as through spatial analysis. Queries – understood as interrogations of the vector data structure – allow the selection of entities based on their descriptive characteristics, while spatial queries make it possible to identify topological and metric relationships such as proximity, intersection, inclusion and distance. These operations form the basis of the main spatial analysis functions, including buffering, overlay operations, surface and distance calculations, distribution analysis and proximity relationships.

Within this context, GIS applications can be understood as tools for analysing and interpreting territory, capable of integrating representation and analysis within a single operational environment. The widespread adoption of platforms such as QGIS, in the open-source domain, and ArcGIS, in the proprietary domain, has contributed to making these tools widely accessible in both academic and institutional contexts, promoting standardisation of formats and data interoperability.

2.3.1.3 - Relational Models and Spatial Databases

The structured organisation of territorial information requires tools capable of managing large amounts of data in a coherent, integrated and queryable manner. In computer science, a database can be defined as an organised collection of interrelated data, designed to represent a specific domain of reality. However, a database does not coincide with a simple data repository: it is managed by a Database Management System (DBMS), that is, a software system that enables the definition, storage, updating and querying of data, ensuring integrity, consistency and access control. Among the various data organisation models, the relational model is the most widely used. It is based on the representation of information through tables (relations) composed of attributes (fields) and instances (records), which are linked through primary keys and foreign keys. The primary key uniquely identifies each instance of an entity, while the foreign key establishes relationships between different tables, formalising the links between elements of the system.

Interaction with a relational database generally takes place through SQL (Structured

Query Language), which allows the definition of table structures, the insertion and modification of data, and the formulation of complex queries. Within the GIS environment, SQL also represents the logical layer through which operations on spatial databases are performed, extending traditional queries to spatial functions.

Database design is conventionally structured into three distinct levels. The conceptual level defines the abstract structure of the domain through formal models, including the Entity-Relationship (E-R) diagram, in which entities, relationships and their attributes are identified. Entities represent classes of similar objects; relationships express the links between entities; attributes describe their properties. A key aspect is the definition of cardinalities, which specify the number of instances involved in each relationship (one-to-one, one-to-many, many-to-many), as well as identifiers, which ensure the uniqueness of instances. Particularly relevant in complex systems are many-to-many relationships, in which a single entity may be associated with multiple instances of another, and vice versa. These relationships cannot be directly represented in the relational model through a single foreign key, but require the introduction of linking tables (or junction tables), which contain the primary keys of the entities involved and make explicit the network-like structure of the information system. Alongside tables physically stored in the database, relational DBMSs allow the definition of views, that is, saved queries that provide derived representations of data without duplicating their content. Views constitute a logical abstraction tool, making it possible to combine multiple tables, select specific attributes or filter records according to defined conditions. In this way, the information system can offer different views of the same dataset, while maintaining a separation between the logical structure and the physical storage structure.

The logical level translates the conceptual model into a relational schema, organising entities into tables and defining keys and integrity constraints. At this stage, restructuring operations on the E-R diagram may be required to ensure coherence and simplicity of the model. The physical level, finally, concerns the actual implementation within the DBMS, including the definition of data types, storage methods and indexing strategies. A central principle in relational design is normalisation, a process aimed at reducing redundancy and undesirable dependencies among attributes, organising tables in such a way as to ensure consistency and logical integrity of the information system. Through normalisation, information is distributed across related but non-redundant structures, making data updating and querying more efficient.

The integration of the relational model with the geographic dimension leads to the development of spatial databases, in which geometry is treated as a structured attribute associated with a specific coordinate reference system. In such environments, it is possible to perform spatial queries directly at the database level, combining attribute conditions and geometric relationships. Among the most widely used open-source solutions is the PostGIS spatial extension for PostgreSQL, which integrates advanced geographic functionalities within a standard relational DBMS; similarly, proprietary platforms such as ArcGIS provide geodatabases capable of managing geometries, relationships and topological constraints.

Within this framework, the relational and spatial structuring of data goes beyond cartographic representation and constitutes a knowledge infrastructure in which enti-

ties, relationships and geometries are formalised according to explicit and queryable rules, enabling a systemic interpretation of interactions between territorial, architectural and production-related phenomena.

2.3.2 - State of the Art on GIS and Information Systems for the Knowledge, Management and Protection of Cultural Heritage

In recent decades, Geographic Information Systems have assumed a central role in the processes of knowledge, management and protection of cultural heritage, evolving from tools for digital cartographic representation into fully integrated information infrastructures. In the cultural heritage field, GIS technology has progressively expanded to include not only the georeferencing of assets and sites, but also the structured organisation of descriptive data, multilevel spatial analysis, integration with three-dimensional models and interoperability with other information systems.

A first category of applications can be identified in systems primarily oriented towards the collection, organisation and access to georeferenced data related to architectural, archaeological or landscape heritage. In these experiences, GIS functions as a platform integrating digital cartography and descriptive records, enabling each territorial element to be associated with a structured set of historical, typological and conservation-related information. Within this context, the work of Santos et al. (2023) proposes a GIS-based system for the inventory and promotion of Portuguese ceramic heritage, in which descriptive records of *azulejo* elements are integrated into a municipal geodatabase, supporting the definition of thematic routes and tourism promotion. The system employs network analysis tools to construct optimised itineraries based on parameters such as accessibility and travel distance, highlighting the role of GIS as an operational tool for cultural planning. Similarly, Simou et al. (2022) develop a georeferenced database for the historical heritage of the city of Rabat, integrating inventory data with multicriteria analysis tools to assess the carrying capacity of the Chellah archaeological site. The approach includes the use of *Kernel Density* models, demonstrating how GIS can support quantitative assessments in the sustainable management of visitor flows. A further field of application is represented by systems oriented towards governance and regulatory protection. The ArchTerr project (Marian & Iacob, 2022) proposes an integrated GIS platform for the protection of archaeological heritage, in which digital cartography, relational databases and regulatory information are connected within a web-based environment accessible to public institutions and private stakeholders. In this case, GIS assumes both an operational and decision-support function, aimed at the preliminary verification of constraints and the reduction of procedural times.

A second area of application concerns the use of GIS as a tool for morpho-typological analysis and diachronic interpretation of the built environment. In this line of research, GIS is used to structure thematic datasets capable of representing not only the location of objects but also their spatial, chronological and constructive relationships. Within this perspective, the work of Mollo et al. (2020) proposes a *Typological GIS* applied to the historic centre of Aversa, aimed at identifying morphological and typological invariants of the built environment. The system allows thematic queries related to

construction period, state of conservation, use, and roofing system, demonstrating how GIS can support multilevel analysis of the urban fabric, from the territorial scale to the building scale. A further development of this approach is represented by the work of Montagnetti (2014; 2016), in which GIS is employed for the analysis of historic centres and archaeological sites through the integration of historical cartography, survey of elevations and stratigraphic recording. In the case of Bagnaia, the system enables the correlation of cadastral data, masonry chronotypes and urban thematic layers, while in the study of Camerata Vecchia the focus is on the organisation of Topographic Units and Masonry Stratigraphic Units within a GIS environment capable of providing a diachronic interpretation of the site. In these experiences, the concept of “vertical GIS” emerges, in which the altimetric and stratigraphic dimensions of the built structure are integrated into the territorial information system.

The evolution of GIS systems applied to cultural heritage has progressively extended to the three-dimensional domain, through integration with geomatic survey techniques and 3D modelling tools. In this context, GIS becomes an environment capable of managing elevation models, volumetric data and complex spatial information. A significant example is provided by Bartolomucci et al. (2012), who experiment with the use of a 3D GIS in the post-earthquake reconstruction of the village of Santo Stefano di Sessanio, employing it as a tool for volumetric verification and control of urban transformations. From a perspective more oriented towards the integration of survey and data management, Gennaro et al. (2018) formalise a workflow connecting UAV acquisition, ortho-photo production, digital terrain modelling, georeferencing and data organisation within a PostgreSQL/PostGIS environment, explicitly defining an entity-relationship model to support the management of archaeological data. These aspects are complemented by the approach proposed by Gennaro et al. (2019), which integrates GIS and multispectral remote sensing techniques for the detection of archaeological evidence in the Etna region, including image processing and the subsequent structuring of results into thematic vector layers. Similarly, Collado et al. (2022) propose an integration between laser scanning survey, HBIM modelling and GIS platforms for the information management of monumental complexes, highlighting the growing convergence between geomatics, 3D modelling and information systems.

More recent research is oriented towards integrated information systems in which GIS, HBIM models and advanced relational databases converge within a single data architecture. Chorro-Domínguez et al. (2025) propose an object-relational infrastructure based on PostgreSQL/PostGIS, capable of bidirectionally synchronising HBIM models and territorial data, integrating environmental and diagnostic variables within a multilevel system. Similarly, Scianna et al. (2016) develop a multiscale system in which the relational database represents the core of integration between a territorial WebGIS and three-dimensional models organised according to a hierarchical structure consistent with the decomposition of the architectural artefact. A further development in terms of interoperability is represented by the work of Colucci et al. (2022), who extend the INSPIRE Data Model to integrate cultural heritage and risk parameters within a 3D GIS system based on PostgreSQL/PostGIS, highlighting the role of standardisation and Levels of Detail (LoD). The contribution by Gorreja et al. (2021) proposes a 3D GIS system

based on CityGML modelling and semantic knowledge modelling for the management of historic settlements in post-earthquake contexts, aimed at the development of interoperable and dynamically updatable platforms.

At the same time, recent literature highlights a growing interest in platforms capable of managing heterogeneous variables – environmental, climatic, morphological and conservation-related – within multilayer territorial models. In this line of research,

Table 1. Comparative analysis of the examined studies on GIS and Information Systems: application domain, methodological approach and objectives.

Authors	Scope / Scale	Methodological Approach	Main Objective
Bartolomucci et al. (2012)	Historic village	3D GIS for post-earthquake reconstruction	Support for urban reintegration and reconstruction planning
Collado et al. (2022)	Monumental complex	HBIM–GIS integration	Information management and maintenance planning
Colucci et al. (2022)	Territorial	INSPIRE-based 3D GIS extension	Risk management and decision support
Chorro-Domínguez et al. (2023)	Monumental Territorial	HBIM–GIS integration through object-relational database	Data integration and interoperability
Gennaro et al. (2018)	Archaeological site	Integrated geomatic workflow within GIS environment	Survey data organisation and management
Gennaro et al. (2019)	Territorial Archaeological	GIS and multispectral remote sensing integration	Detection and analysis of archaeological features
Gorreja et al. (2021)	Historic village	3D GIS and semantic modelling (CityGML)	Integrated information management in post-seismic context
Mangiameli et al. (2022)	Territorial	Multilayer spatial analysis	Environmental vulnerability assessment
Marian & Iacob (2022)	Territorial	GIS-based regulatory database	Decision support and heritage protection
Mollo et al. (2020)	Historic centre	Typological GIS	Morphological and typological analysis
Montagnetti (2013)	Historic centre	Vertical GIS and historical cartography integration	Diachronic analysis of built heritage
Montagnetti (2016)	Archaeological site	GIS-based organisation of topographic and stratigraphic units	Historical-stratigraphic analysis
Santos et al. (2023)	Urban Municipal	Inventory-based GIS and network analysis	Cultural valorisation and route planning
Scianna et al. (2018)	Multiscale	WebGIS and 3D modelling integration	Integrated territorial information system
Simou et al. (2022)	Urban Archaeological site	GIS with multi-criteria analysis and Kernel Density	Visitor flow management and sustainability

studies such as Mangiameli et al. (2022) integrate the spatial analysis of climatic and environmental variables within a GIS environment to assess territorial vulnerability. The multilayer approach allows the overlap of climatic, morphological and anthropogenic data, producing thematic maps useful for understanding risk factors and interactions between heritage and environment. Similarly, in contributions focused on risk management and resilience, such as Colucci et al. (2022), the integration of cultural data and environmental datasets demonstrates how GIS can function as a decision-support platform at a supra-local level.

For comparative purposes, Table 1 provides a synthesis of the analysed contributions, relating scale of analysis, methodological approach and research objectives.

From the analysis of the literature, a progressive increase in the technical and methodological complexity of GIS applications for cultural heritage emerges. The examined experiences highlight a growing expansion of analytical and management capabilities, particularly in urban, archaeological and monumental contexts. At the same time, these contributions show how attention is often focused on the individual building, the historic centre or specific operational objectives – such as valorisation, risk management or design verification – while less developed are information models oriented towards the systemic formalisation of territorial relationships among different categories of assets, resources and processes. Within this context, the integration of territorial scale, production dimension and relational data organisation represents a field of research still in development, within which the present work is positioned.

2.4 - Digital Architectural Survey: Theoretical Framework and Methodological Developments

2.4.1 - Methodological Principles and Tools of Digital Survey

Architectural survey is traditionally understood as a knowledge-based process aimed at the understanding, measurement and representation of the building. As stated by Cundari (2013), “survey is the set of procedures and investigations useful for retracing the process of construction of the work”, thus configuring itself as a key tool for the documentation and interpretation of architecture. Surveying a building therefore means investigating its overall configuration, historical complexity, geometric and dimensional characteristics, formal and constructive aspects, state of conservation and relationships with the context, through a process that integrates measurement, analysis and interpretative synthesis. The disciplinary tradition of architectural survey, widely consolidated in major reference manuals (Bertocci & Bini, 2012; Docci & Maestri, 2009), emphasises that measurement is not merely a metric act, but a preliminary phase in the construction of a knowledge model, in which data are selected, organised and structured according to the objectives of the investigation. Within this perspective, survey is not a simple reproduction of reality, but a critical process of interpretation that requires the prior definition of a survey project capable of establishing which data to acquire, with which instruments and to what level of accuracy. Traditionally, the discipline distinguishes be-

tween direct survey and indirect or instrumental survey; however, over the last two decades, the introduction of high-density digital 3D acquisition technologies has profoundly transformed operational methods, redefining the relationship between measurement, representation and modelling. Contemporary survey can therefore be understood as an integrated process in which laser scanning and photogrammetric techniques contribute to the construction of complex three-dimensional models capable of accurately representing both the morphology and material characteristics of architecture.

The three-dimensional model derived from the survey functions as an information platform supporting subsequent analyses. It can serve as a basis for structural modelling and vulnerability assessment (Aoki et al., 2019; Mondello et al., 2019; Zerlenga et al., 2022), for preliminary analyses of static and seismic behaviour (Colapietro et al., 2026; Micelli et al., 2020), for environmental or hydraulic simulations (D'Agostino et al., 2021; Pennisi et al., 2022), for heritage information modelling and management processes (Croce et al., 2021), as well as for digital dissemination and public engagement (Aiello et al., 2019; Pupi et al., 2026). In this perspective, the selection of acquisition techniques and the definition of required accuracy levels assume a strategic role in relation to the cognitive and operational objectives of the investigation.

The most widely used technique in instrumental three-dimensional survey is terrestrial laser scanning (TLS), which enables the mass acquisition of points through the emission of laser pulses and the measurement of distance to the surveyed surfaces. For each recorded point, both distance and orientation of the emitted laser beam are measured, allowing the three-dimensional reconstruction of the object in the form of a high-density point cloud. According to the measurement principle, laser scanning systems can be classified into optical triangulation systems, time-of-flight systems and phase-shift systems. Triangulation devices are mainly used for small-scale objects, due to the high accuracy achievable at short distances, whereas time-of-flight and phase-shift systems are more commonly employed in architectural and urban surveys, as they allow the acquisition of large portions of buildings with millimetric accuracy and adequate spatial resolution.

TLS acquisition is performed from fixed stations, requiring prior planning of scan positions in order to minimise shadow areas caused by occlusions, overhangs or morphological complexity. The quality of the final model therefore depends not only on instrumental characteristics but also on survey design and on the alignment of individual scans.

Alongside static systems, mobile mapping devices based on SLAM (Simultaneous Localization and Mapping) algorithms have become increasingly widespread, enabling continuous acquisition during sensor movement. These systems simultaneously estimate sensor position and environmental geometry, significantly reducing operational time compared to traditional surveys. However, comparative studies have highlighted performance differences compared to TLS systems in terms of metric stability and overall accuracy (Lehtola et al., 2017; Masiero et al., 2018). The incremental nature of alignment may generate cumulative errors (drift), making the planning of closed trajectories and the control of metric quality essential.

Multi-image photogrammetry is now one of the main methods of three-dimensional

acquisition in architectural contexts. Based on the principles of stereoscopic reconstruction, it has undergone a significant transformation with the introduction of Structure from Motion (SfM) algorithms, which allow the automatic reconstruction of 3D geometry from sets of overlapping digital images. In contemporary architectural survey, photographic acquisition is no longer merely visual documentation, but a structured phase of the metric process, in which image acquisition planning, overlap percentage and lighting conditions are crucial for reconstruction quality. Automatic matching algorithms identify homologous points between images, reconstructing their spatial position and generating a three-dimensional point cloud, which can subsequently be transformed into a textured geometric model. In this perspective, architectural photomodelling (De Luca, 2011) is not limited to an automated reconstruction process but involves an interpretative and critical phase in which the digital model becomes a tool for understanding the building. Metric quality depends significantly on acquisition conditions: adequate overlap, stable camera parameters and homogeneous lighting are essential requirements. Low-texture or highly reflective surfaces may reduce matching reliability, requiring careful planning and, where necessary, the use of targets for correct model scaling.

The use of UAV (Unmanned Aerial Vehicle) systems has further expanded the potential of photogrammetry, enabling image acquisition from elevated or otherwise inaccessible viewpoints. In architectural and urban contexts, UAV systems allow more complete documentation of roofs and vertical elements, facilitating integration with data acquired through terrestrial laser scanning systems, as demonstrated in applications to complex vertical architectures (Rodriguez-Navarro et al., 2018).

The widespread adoption of three-dimensional technologies has brought the issue of accuracy and reliability of acquired data to the centre of methodological debate. The quality of a survey must be evaluated in relation to the scale of representation and the objectives of the investigation, and not solely in quantitative terms such as point cloud density. Instrumental precision, local noise and the propagation of systematic errors affect the model differently depending on whether it is intended for graphical representation, morphological analysis or structural modelling. In static systems, error is generally related to instrument precision and scan alignment; in mobile systems based on SLAM algorithms, drift – the cumulative propagation of error along the acquisition path – becomes particularly relevant. Recent studies show that closed trajectories and sufficient overlap can significantly reduce these effects, although differences remain compared to static systems in terms of global accuracy (Keitaanniemi et al., 2021; Mandelli et al., 2017; Piniotis et al., 2020). The metric evaluation of three-dimensional data becomes particularly decisive when the survey provides the basis for structural or vulnerability analyses. In such cases, the detectability threshold of geometric discontinuities, deformations or out-of-plumb conditions must be consistent with the required scales of analysis and with the parameters of the numerical models employed (Aoki et al., 2019; Colapietro et al., 2026; Zerlenga et al., 2022). The definition of the required level of detail is therefore not a purely technical parameter, but a design choice closely connected to the knowledge objectives of the investigation.

Within this framework, multi-sensor integration emerges as an established opera-

tional paradigm: the combination of TLS, photogrammetry and SLAM systems allows the limitations of each technique to be compensated, improving the completeness and geometric consistency of the three-dimensional model (D'Agostino et al., 2022; Tucci et al., 2018). Survey design therefore becomes a strategic phase of the process, in which instruments, required accuracy and research objectives are consciously integrated.

2.4.2 - State of the Art on the Survey of Complex Architectures

The three-dimensional digitisation of architectures characterised by high morphological and spatial complexity has long been a well-established field of research within the international scientific landscape. The term “complex architectures” refers to artefacts distinguished by volumetric articulation, irregular or difficult-to-access internal spaces, geometric discontinuities, significant vertical development, or the coexistence of structural and technological components that interfere with acquisition operations. This category includes underground environments, towers, bell towers, fortified structures, stratified historic buildings and architectural organisms characterised by a high degree of spatial articulation.

In such contexts, complexity translates into a series of recurring operational challenges: narrow spaces, complex circulation paths, poor lighting conditions, discontinuous surfaces and the presence of obstacles that limit movement and generate occlusions. Studies conducted in environments with these characteristics have shown that survey results are strongly influenced not only by the nominal performance of instruments, but also by the actual conditions of use and by the ability to adapt procedures to the specific context (Chiabrando et al., 2018; Mandelli et al., 2017; Salgues et al., 2020). In particular, with regard to narrow spaces, the need to increase the number of TLS stations or to plan closed and overlapping trajectories in mobile systems becomes a key requirement to ensure completeness and geometric consistency of the model.

A second aspect concerns the comparison between acquisition systems in relation to environmental complexity. Several studies have shown that, in complex and heterogeneous contexts, TLS systems generally ensure greater metric stability, albeit with longer operational times and greater rigidity in planning. Mobile systems based on SLAM, on the other hand, allow for a significant reduction in acquisition time and greater operational flexibility, while presenting potential limitations related to error propagation and drift management (Lehtola et al., 2017; Keitaanniemi et al., 2021; Masiero et al., 2018; Piniotis et al., 2020). Environmental complexity therefore becomes the key parameter for evaluating the balance between operational efficiency and metric accuracy.

A further recurring aspect in the literature concerns the need for integrated approaches. In the presence of highly articulated environments or contexts characterised by significant variations in scale and accessibility, the combination of multiple techniques – TLS, mobile systems and photogrammetry – emerges as the most robust methodological solution, capable of compensating for their respective limitations and improving the completeness of the three-dimensional model (Colapietro et al., 2026; D'Agostino et al., 2022; Marziali & Cailotto, 2026; Perfetti et al., 2023). Similarly, in fortified or stratified contexts, where complexity arises from the superposition of construc-

tion phases and limited accessibility to specific parts of the building, the integration of acquisition techniques has proven to be essential for obtaining coherent and reliable models (Pancani & Bigongiari, 2020).

Alongside morphological and operational challenges, the literature highlights a further dimension of complexity related to the management of large-scale point clouds and the scale of intervention. In projects involving complex structures or large building ensembles, the difficulty lies not only in data acquisition but also in its organisation, integration and validation. The presence of large-scale point clouds, the need to align heterogeneous datasets and the management of different levels of detail introduce issues that are not only metric but also computational and methodological, with implications for information modelling and heritage management processes (Di Stefano et al., 2021). Complexity therefore assumes a dual role: on the one hand, as a spatial and morphological condition affecting acquisition strategies; on the other, as a management-related factor requiring a carefully planned design of the entire survey process.

Table 2. Selected studies addressing the digital survey of complex architectural environments, highlighting the relationship between spatial complexity, acquisition strategy and methodological integration.

Author (year)	Building type/ Case study	Technologies employed	Main critical issues addressed	Methodological focus
Chiabrando et al. (2018)	Complex cultural heritage building	TLS + SfM	Articulated spatial configuration	Integration of heterogeneous datasets
Colapietro et al. (2026)	Complex heritage building	Integrated survey approach	Large-scale articulated morphology	Optimisation of acquisition strategy
D'Agostino et al. (2022)	Hypogeal architectural environment	TLS + SfM	Irregular morphology and limited accessibility	Comparative metric validation
Di Stefano et al. (2021)	Large architectural complex	Integrated 3D survey approach	Extensive datasets and multi-scale integration	Information management and validation
Mandelli et al. (2017)	Narrow architectural spaces	TLS	Restricted geometry and occlusions	Scan planning strategies
Marziali & Cailotto (2026)	Articulated architectural spaces	Integrated survey approach	Variations in scale and accessibility	Multi-sensor workflow definition
Pancani & Bigongiari (2020)	Fortified architectural complex	TLS + SfM	Stratified construction and accessibility constraints	Integrated geometric documentation
Perfetti et al. (2023)	Historic complex building	Integrated survey approach	Morphological complexity	Workflow development for articulated contexts
Salgues et al. (2020)	Complex heritage architecture	SLAM-based Mobile Mapping	Restricted spaces and operational constraints	Rapid acquisition in complex environments

2.4.2.1 - State of the Art on the Survey of Towers

The three-dimensional digitisation of bell towers falls within the broader field of complex architectures, while representing a specific case characterised by its own distinct challenges. Due to their pronounced verticality, slender proportions, the presence of bell systems and the internal articulation of spaces, towers present operational issues that differ from those of other monumental structures. Their considerable height, proximity to adjacent buildings and the difficulty of accessing upper sections significantly influence the selection of survey methodologies and technologies.

The internal environments of towers present particularly critical operational conditions, mainly related to continuous vertical development and the reduced cross-section of spaces. Spiral staircases, intermediate landings, superimposed floors and the presence of bell structures create a sequence of environments with limited freedom of movement, strong occlusions and frequent geometric discontinuities. These conditions are often compounded by poor natural lighting – or, in some cases, the complete absence of light – which affects both the quality of photogrammetric acquisition and the operational management of survey campaigns. In such contexts, survey planning plays a decisive role, as the distribution of scan stations or the definition of acquisition trajectories directly influences the completeness and metric stability of the three-dimensional model. The integrated survey of the bell tower of the Municipality of Montanaro has shown how the combined use of TLS and mobile systems based on SLAM allows a balance between accuracy and operational speed, using static scans as a metric reference for validating data acquired in motion (Teppati Losè et al., 2021). Subsequent applications to complex cultural heritage have also confirmed the importance of methodological integration between different technologies and of prior survey planning to ensure metric consistency along the vertical development of the structure (Teppati Losè et al., 2022).

While the survey of internal environments is constrained by reduced cross-sections and vertical continuity, the acquisition of external surfaces presents different challenges, closely related to height and urban configuration. Pronounced verticality, the presence of projections, cornices and spires, as well as proximity to adjacent buildings, create conditions of occlusion and difficulties in framing that directly affect the completeness and metric reliability of the three-dimensional model. In photogrammetric surveys, the main critical issues concern error control in upper areas and the accurate representation of the verticality of the structure, especially when acquisition is carried out from ground level and at a significant distance from the object (De Marco, 2020; Molina Sánchez et al., 2021). The use of UAV systems has proven to significantly improve the documentation of upper parts, enabling image acquisition from elevated viewpoints and reducing perspective distortions (Rodríguez-Navarro et al., 2018). In applied studies on monumental towers, the combination of UAV survey, TLS and terrestrial photogrammetry has made it possible to obtain more complete and consistent three-dimensional models, improving the representation of roofs and spires and the overall quality of digital documentation (Ricci & Pasquali, 2022; Teppati Losè et al., 2022). In this perspective, the integration of different techniques emerges as a necessary operational condition to ensure geometric continuity between the base and the top of the tower.

The availability of metrically reliable three-dimensional models makes it possible to

Table 3. Overview of recent studies on the digital survey of towers, highlighting case studies, integrated acquisition strategies and structural applications of 3D survey data in vertically developed heritage structures.

Author (year)	Case study	Technologies employed	Main critical issues addressed	Survey purpose
Aoki et al. (2019)	Torre degli Smeducci and cathedral belltower at San Severino Marche	Integrated 3D survey + FEM modelling	Structural vulnerability and dynamic behaviour	Modal and dynamic structural analysis
Contrafatto et al. (2026)	Masonry belltower (Etna area case study)	TLS + SLAM-based Mobile Mapping + FEM modelling	Geometric uncertainty in structural modelling	Finite element modelling for structural assessment
De Marco (2020)	Pavia Clock Tower	SfM photogrammetry	Verticality control and upper sections	External geometric documentation
Galizia et al. (in press)	Masonry belltower (Etna area case study)	Integrated 3D survey approach	Morphological interpretation and vertical articulation	Digital interpretation and heritage enhancement
Micelli et al. (2020)	Soletto's belltower	Integrated 3D survey + structural analysis	Seismic capacity assessment	Structural vulnerability evaluation
Molina Sánchez et al. (2021)	Basilica of San Francesco and church of San Carlo belltowers in Ravenna	SfM photogrammetry	Verticality and geometric control	External 3D restitution
Ricci & Pasquali (2022)	Round Tower della Ragnaia in Fiesole	TLS + UAV + SfM	Roofs and upper architectural elements	Comprehensive 3D documentation
Teppati Losè et al. (2021)	Montanaro belltower	TLS + SLAM-based Mobile Mapping + UAV	Internal vertical development and limited accessibility	Integrated 3D model generation
Teppati Losè et al. (2022)	Montanaro belltower	Integrated survey approach	Vertical continuity and multi-sensor integration	Workflow optimisation
Zerlenga et al. (2022)	San Michele Arcangelo belltower in Caserta	Integrated 3D survey + structural modelling	Structural vulnerability	Structural assessment

extend the use of survey beyond geometric documentation, turning it into a basis for structural analysis and vulnerability assessment. Several studies have shown how the quality and completeness of the survey directly affect the accuracy of numerical models used for modal and seismic analysis of masonry towers (Aoki et al., 2019; Micelli et al., 2020; Zerlenga et al., 2022). In this field, the integration of high-density digital survey and finite element modelling allows for a significant reduction in geometric uncertainty, focusing attention on mechanical variables and boundary conditions influencing structural behaviour (Contrafatto et al., 2026). The three-dimensional survey thus becomes a preliminary and indispensable phase for the construction of numerical models consistent with the actual morphology of the structure.

Alongside its use for structural purposes, the digital model derived from survey also assumes an interpretative and communicative role. Bell towers, as prominent elements of the urban skyline and identity markers within the territory, can be investigated not only in their technical dimension but also in their historical and cultural significance. From this perspective, three-dimensional modelling becomes a tool for critical interpretation of the architectural organism, capable of integrating metric data, morphological analyses and interpretative representations, as well as supporting processes of heritage enhancement and digital dissemination (Galizia et al., in press). The tower thus emerges not only as an object of measurement, but as a complex system in which survey, analysis and interpretation converge in a multilevel knowledge process.

2.4.2.2 - Digital Survey of Glazed Ceramic Surfaces

Glazed ceramic surfaces introduce specific challenges in digital survey due to their reflective optical behaviour. Previous studies on problematic artefacts, translucent materials, reflective objects, and glossy heritage surfaces have highlighted how specular reflections, variable radiometric responses, and material finish can affect photogrammetric reconstruction, 3D scanning, and the interpretation of textured models (Nicolae et al., 2014; Angheluță & Rădvan, 2020; Frost et al., 2023; Kim et al., 2025). In the case of ceramic spires, these issues are compounded by the height of the elements, their curved geometry, and the frequent impossibility of direct access, reinforcing the need for an integrated survey strategy combining different acquisition techniques.

For this reason, the survey strategy adopted in this research combines TLS, MLS, and UAV-based photogrammetry, not only to improve geometric completeness, but also to compensate for the limitations that each technique may encounter when applied to glazed and hardly accessible architectural surfaces.



Chapter 3 - Objectives

The research is structured around a coherent system of hypotheses, research questions and research objectives, aimed at the scientifically rigorous development of an integrated knowledge model for wedge-shaped glazed ceramic spires in Sicily.

Although this heritage represents a highly distinctive element of the regional architectural landscape and of the skyline of many urban centres, it is currently only partially documented and rarely addressed through systematic studies. Its specialised nature, the elevated position of these elements and the vulnerability of glazed surfaces contribute to making it a relatively under-investigated heritage, potentially exposed to degradation processes that are not adequately monitored.

Within this framework, the need emerges to structure a knowledge system capable of integrating documentation, survey and territorial analysis, in order to prevent this heritage from remaining marginal within conservation and planning processes.

The methodological approach therefore aims to move beyond a purely descriptive reading of the architectural artefact, interpreting it instead as the expression of a complex territorial system, in which raw materials, production processes, construction techniques and geographical distribution are closely interconnected.

3.1 - Research Hypothesis

The research is based on the hypothesis that wedge-shaped glazed brick spires found across Sicily do not constitute isolated episodes or contingent decorative solutions, but rather represent the visible expression of a structured production and territorial system that is currently only partially recognised. It is further hypothesised that the construction technique based on the systematic use of wedge-shaped ceramic elements coated with glaze is widely and recognisably distributed within Sicily, configuring itself as a feature deeply rooted in the regional context and as a distinctive element of the architectural landscape.

In the absence of a systematic structuring of morphological, production-related

and territorial data, this heritage risks remaining undervalued within conservation and planning processes. The verification of the hypothesis therefore requires an integrated approach capable of relating:

- Historical and archival documentation and national cataloguing standards (ICCD);
- Digital survey and morphological analysis;
- Relational modelling of both spatial and non-spatial data;
- The use of GIS technology through free and open-source software for spatial analysis.

Only through this integration is it possible to restore a systemic dimension to the phenomenon and make it fully legible within the broader framework of regional cultural heritage.

3.2 - Research Questions and Research Objectives

Considering the stated hypothesis, the research is structured around four main questions. Each research question is associated with a structured set of operational objectives aimed at verifying the hypothesis and developing the proposed methodological framework.

Research Question 1

Typological characteristics and recognition of the phenomenon:

- What are the morphological, material, decorative and constructive characteristics of wedge-shaped glazed brick spires in Sicily?
- Can this construction technique be recognised as a structured territorial specificity?

Research Objective 1

Analysis, census and systematisation. The research aims to:

- Develop a systematic census of bell towers with wedge-shaped glazed brick spires in Sicily;
- Analyse their geometric, constructive and decorative patterns;
- Organise and structure the data according to a model consistent with ICCD standards, verifying the compatibility between the designed database and national cataloguing frameworks;
- Contribute to the definition of an information schema capable of interacting with official heritage cataloguing systems.

Research Question 2

Territorial relationships and production dynamics:

- What relationships exist between spires, towers, ceramic production centres, quarries and the territorial context?
- Is it possible to identify correlations between geographical proximity, the presence of production centres and the diffusion of the phenomenon across time and space?

Research Objective 2

Development and validation of a relational and spatial model. The research aims to:

- Design an entity-relationship conceptual model distinguishing towers, spires, production centres, quarries and municipalities;
- Implement a normalised relational database in a PostgreSQL/PostGIS environment, structured through dedicated tables, many-to-many relationships, controlled lookup tables and referential integrity constraints;
- Integrate the database with a GIS application to perform proximity, distance and spatial distribution analyses;
- Introduce the temporal dimension of data to identify possible phases of chronological diffusion;
- Verify the hypothesis of a correlation between raw material availability, the presence of production centres and the spatial distribution of spires;
- Lay the groundwork for integrating the database with other systems aimed at the prevention and protection of this heritage from natural and man-made risks.

Research Question 3

Digital survey, documentation and conservation:

- How can digital survey contribute to the documentation, knowledge and conservation of ceramic spires?

Research Objective 3

Definition of an integrated documentation workflow. The research aims to:

- Test integrated survey techniques (terrestrial and UAV photogrammetry, terrestrial laser scanning and mobile laser scanning) for the documentation of spires;
- Produce high-resolution three-dimensional models suitable for morphological analysis and for understanding construction techniques;
- Use digital survey as a 3D digital archive supporting preventive conservation, monitoring and intervention planning.

Research Question 4

Replicability of the model:

- Can the developed methodological model be applied to other territorial contexts or to different types of architectural artefacts?

Research Objective 4

Formalisation and transferability of the workflow. The research aims to:

- Formalise an integrated workflow linking digital survey, relational database structures and GIS functionalities;
- Distinguish elements specific to the Sicilian case from those that are methodologically generalisable;
- Demonstrate the transferability of the model to different architectural heritage contexts, materials or construction systems, including in other geographical settings.

The set of questions and objectives outlined above defines the logical framework within which the research is developed. The following chapter describes the methodological path adopted for their verification, detailing the tools, procedures and implementation phases of the integrated information system.



Chapter 4 - Methodology

This thesis aims to define an integrated and multiscale methodology aimed at establishing new guidelines for the conservation of cultural heritage. The approach proposes a knowledge system capable of integrating the descriptive, informational, geometric and territorial dimensions of the heritage under study, ranging from cataloguing to digitalisation and making use of advanced survey technologies. The ultimate objective is the safeguarding of the heritage asset from potential man-made and environmental risks, ensuring its transmission to future generations.

Wedge-shaped glazed brick spires are analysed as elements belonging to a complex system in which production factors, raw material availability, construction techniques and patterns of territorial diffusion interact. The investigation is therefore oriented towards a model capable of structuring and querying data in a relational manner, moving beyond an exclusively typological reading. Digital survey and information modelling constitute a central component as tools for interpreting heritage. The adopted approach is situated within the disciplinary field of Architectural Drawing and Representation, in which survey constitutes the foundational act of architectural knowledge and model construction – whether geometric or informational – acts as a mediating device between object, representation and understanding. The selection, organisation and hierarchical structuring of data thus become interpretative processes through which heritage is translated into a knowledge structure. Relational modelling and database design are also conceived as forms of representation: tools capable of making explicit relationships, hierarchies and connections that would otherwise remain implicit.

The methodological framework is structured across several interrelated domains:

- A cataloguing and descriptive domain, oriented towards the formalisation of collected information according to nationally recognised standards (ICCD);
- An information-relational domain, aimed at conceptual modelling and the implementation of a structured database in a PostgreSQL/PostGIS environment;
- A territorial-spatial domain, developed through integration with GIS-based analytical functionalities for analysing relationships between spires, towers, production

centres, quarries and the geographical context;

- A geometric-morphological domain, based on the use of digital survey for the documentation and analysis of the constructive characteristics of spires.

These domains are not conceived as autonomous or sequential, but as components of a unified methodological system, in which each contributes to the verification of the research hypothesis and to the construction of a systemic interpretation of the phenomenon (Figure 1).

The integration of information structuring, digital survey and territorial analysis restores the morphological, relational and territorial dimensions of the heritage, highlighting its role within broader production networks and historical-geographical dynamics.

The adopted methodology is conceived as a replicable model, based on the coherent combination of tools and procedures, aimed both at the understanding of the Sicilian case study and at defining an approach applicable to other specialised architectural heritage contexts.

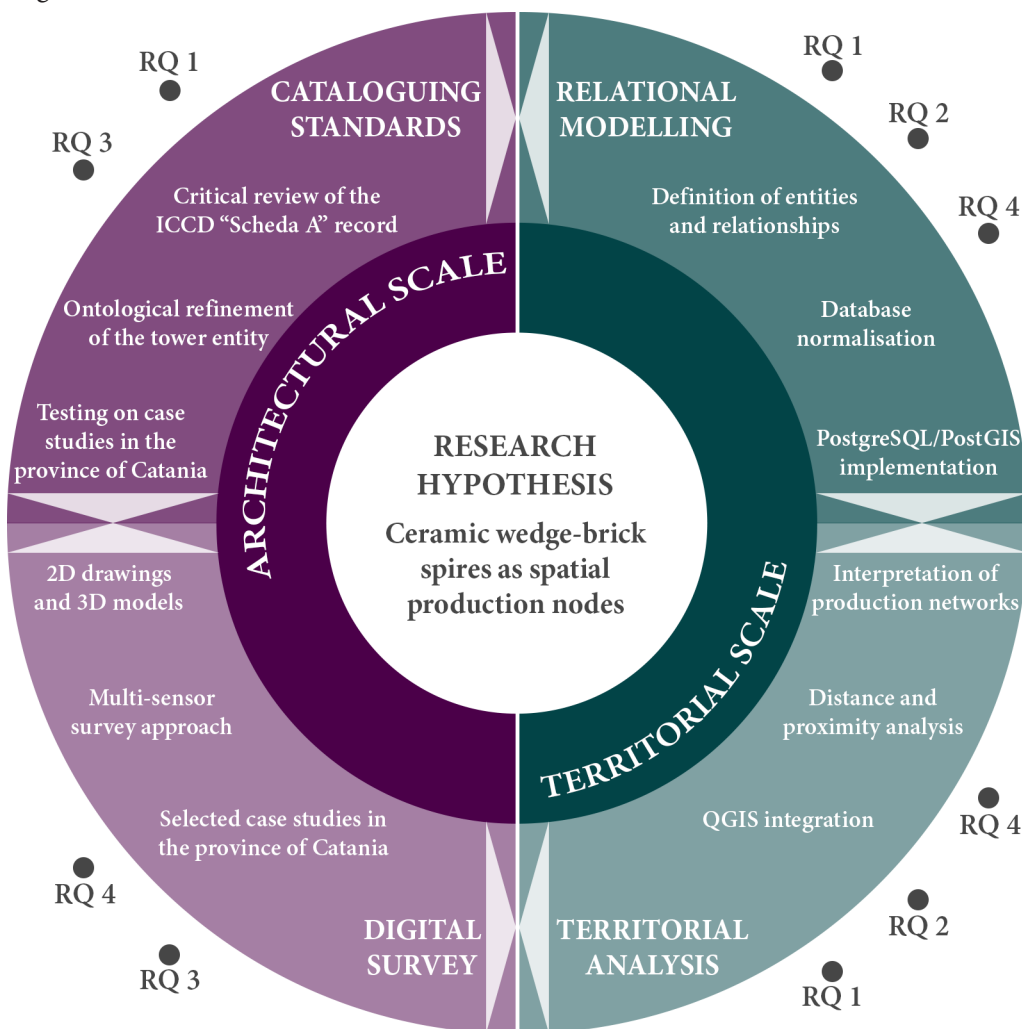


Figure 1. Diagram of the proposed methodology and its relationship with the research questions (RQ).

Domain 1 – Cataloguing Standards and Descriptive Structuring

The methodological process includes the planning and structuring of acquired data and information, as well as the analysis and interpretation of all physical, technical, historical and descriptive characteristics.

The comparison with national cataloguing standards served as the starting point for the descriptive formalisation of the heritage under study. In particular, the analysis of the ICCD “Scheda A”, intended for the cataloguing of architectural heritage, was adopted as the initial reference for organising information related to the analysed towers. The application of the Scheda A highlighted several limitations related to the morphological and functional specificity of the towers under investigation. The structure of the record, conceived for the overall description of the architectural organism, did not allow for a sufficiently articulated representation of the tower as a vertical entity endowed with morphological and constructive autonomy with respect to the building complex to which it belongs. The absence of a clearly structured ontological framework and the rigidity of certain descriptive fields limited the systematic representation of typological and constructive characteristics relevant to the aims of the research.

These issues are part of the broader process of revision of the national cataloguing system initiated by ICCD, aimed at reorganising cataloguing records according to an ontological structure oriented towards interoperability and semantic data modelling. Within this process, the research contributed to the definition of the ontological domain related to towers, through the identification of entities and properties consistent with the descriptive requirements emerging from the analysis of the case studies. At the same time, a testing phase of the new cataloguing structure was carried out on a selected sample of towers with ceramic spires located in the Etna area. This experimentation made it possible to verify the adequacy of the new ontological framework with respect to the morphological complexity of towers and to test its capacity to describe more flexibly the relationships between the different components of the architectural organism and the reference context¹. This phase has methodological relevance, as it allows a comparison between an evolving descriptive system and the analytical needs of the research, highlighting both its potential and its limitations with respect to the representation of the territorial and production-related relationships that constitute the core of the research hypothesis.

Domain 2 – Relational Modelling and Database Implementation

The descriptive formalisation of heritage, structured according to cataloguing standards, constitutes a fundamental step in the normalisation and systematisation of information related to the individual asset. However, the research hypothesis requires a further level of analysis, oriented not only towards the description of the architectural

¹ Protocollo di Intesa per la realizzazione del progetto dal titolo “Aggiornamento e sviluppo di metodologie di catalogazione e documentazione per la conoscenza del patrimonio artistico e architettonico” tra l’Istituto Centrale per il Catalogo e la Documentazione del Ministero della Cultura, rappresentato dall’arch. Carlo Birrozzi, e l’Università degli Studi di Catania – Dipartimento di Ingegneria Civile e Architettura, con referente la prof.ssa Mariateresa Galizia, stipulato in data 13/03/2026.

object, but towards the understanding of the relationships that connect it to the territorial system. The phenomenon under study cannot be interpreted solely through the cataloguing of the individual asset, as its configuration results from the interaction between production factors, raw material availability, settlement dynamics and construction processes. This leads to the need for a structure capable of making these interconnections explicit and of organising data to support cross-referencing queries and systemic interpretations. The transition from a descriptive model to a relational model therefore represents a necessary methodological step. While the cataloguing record organises information around the individual asset, the relational database enables the domain of study to be structured into distinct entities and their interconnections to be explicitly defined, formalising the systemic nature of the phenomenon.

The construction of the relational model was preceded by a conceptual modelling phase aimed at identifying the relevant entities and the relationships structuring the domain of study. This phase was intended to translate the research hypothesis into a formal configuration capable of explicitly representing the different levels contributing to the definition of the analysed phenomenon. Domain analysis led to the identification of a set of main entities corresponding to the elements involved in the configuration of the territorial system under investigation. These entities include towers, ceramic spires, production centres, raw material quarries and municipalities. Each entity was considered as an autonomous unit characterised by specific attributes, describing its morphological, material and locational features at a level of detail consistent with the research objectives.

Particular attention was given to the definition of relationships between entities, in order to represent the interconnected nature of the phenomenon. In several cases, these relationships take the form of many-to-many associations, reflecting the complexity of production and territorial dynamics. The formalisation of these relationships constitutes a central component of the model, as it allows connections to be made explicit that would not emerge from an isolated description of individual elements.

The logical design phase translated the conceptual model into a coherent and formally organised structure oriented towards relational data management. The schema was defined to keep the identified entities distinct, preserving their autonomy while ensuring the possibility of representing their interconnections. The organisation of the model is based on normalisation principles aimed at reducing data redundancy and ensuring internal consistency. The separation of entities into distinct structures avoids data duplication and ensures that each piece of information is stored in the most appropriate context. This approach enhances the semantic clarity of the model and facilitates its long-term updating. Relationships between entities were formalised to make explicit the structural links identified during the conceptual phase, maintaining a clear distinction between entity attributes and information derived from their interconnections. In this way, the system structures data according to a relational logic that reflects the interpretative framework of the research.

The implementation phase finally translated the logical design into a relational database. The choice of an environment based on PostgreSQL, integrated with the PostGIS spatial extension, addresses the need to combine relational data management with the

geographical dimension of the phenomenon under study. The adoption of a relational system ensures consistency between entities and relationships defined in previous phases, guaranteeing data integrity and enabling structured querying. The integration of the spatial extension allows geometric components to be associated with territorial entities, incorporating the locational dimension as an integral part of the information structure. The implementation within a relational and spatial environment thus represents the operational consolidation of the methodological model: the physical structure of the database reflects the conceptual configuration of the domain and makes the identified relationships effectively analysable within the system, laying the groundwork for subsequent territorial analyses.

Domain 3 – Territorial Analysis and GIS Application

The territorial dimension of the research hypothesis requires the integration of the relational data structure with spatial analysis tools. The phenomenon under study is reflected in the geographical distribution of the tower/spire system, in the location of production centres and in their relationship with raw material supply areas. The spatial dimension does not represent an additional layer of the investigation, but a structural component of its interpretation.

The information infrastructure was therefore integrated within a GIS application, by linking the database developed and managed in a PostgreSQL/PostGIS environment with QGIS software. This configuration allows geographical location to be treated as an analytical variable, associating geometric components with entities that can be queried according to spatial criteria. The integration of alphanumeric and spatial data enables the exploration of relationships between spires, towers, production centres and quarries not only from a descriptive perspective, but also in terms of distribution, distance and proximity. In this way, the geographical component becomes part of the logical structure of the system, enabling the analysis of territorial configurations and potential correlations between location and production dynamics.

The main operations considered within the territorial analysis include distance analysis between entities, proximity analysis and the observation of distribution patterns at both local and regional scales. These tools make it possible to verify the presence of concentrations or spatial clusters that may be associated with production centres or the availability of raw materials.

The GIS environment therefore assumes a clearly defined methodological role: not merely as cartographic support, but as an analytical tool integrated with the relational model, through which the territorial structure of the phenomenon can be systematically investigated.

Domain 4 – Digital Survey for Documentation, Analysis and Modelling

Digital survey constitutes one of the key methodological components of the research, as it provides the knowledge base for the morphological, constructive and dimensional analysis of towers with wedge-shaped brick spires. In line with the disciplinary framework of Architectural Drawing, survey is understood as a process of knowledge construction through measurement and representation.

The survey campaign focused on five bell towers within the Etna area, including the ecclesiastical complexes of which they form an integral part. The selection of the sample made it possible to analyse cases characterised by different morphological configurations and accessibility conditions. In some situations, logistical constraints and access limitations prevented the execution of complete surveys, making it necessary to adapt acquisition strategies according to operational conditions.

The adopted approach was based on the integration of different digital survey techniques, selected according to site characteristics and research objectives. The main outcome of this phase is the three-dimensional model, based on point clouds acquired through terrestrial laser scanning as the primary metric reference and integrated with data from mobile mapping systems and photogrammetric surveys conducted both from ground level and from UAV platforms. This multi-sensor integration made it possible to combine metric accuracy with geometric completeness. In two cases, additional acquisitions were carried out using structured-light laser scanning on selected ceramic elements of the spires, aimed at documenting individual components in detail and reconstructing their geometric and dimensional characteristics.

The acquisition phase produced high-density point clouds and textured three-dimensional models, representing the geometric, technical and semantic reconstruction of the object of study. From these models, two-dimensional outputs such as plans, sections and elevations were subsequently derived, supporting morphological interpretation and dimensional verification. The three-dimensional models and derived outputs can be stored within the designed database and linked to the GIS environment, enabling synchronised and integrated access to the data. This integration provides significant advantages for the management of information related to the cultural heritage asset and for its conservation.

The models enabled the analysis of spire geometry, the placement of wedge-shaped bricks and the dimensional relationships between the different components of the architectural organism. Furthermore, they provided the geometric data required for subsequent structural modelling, acting as a metric basis for potential numerical analyses of structural behaviour.

Finite Element (FE) models were developed, and the dynamic properties of the investigated towers (natural frequencies and mode shapes) were evaluated. This made it possible to carry out preliminary assessments of the displacement behaviour of the spires when subjected to the oscillatory motion of the supporting tower, identifying a kinematic behaviour that appears, in most cases, to be characterised by rigid-body motion.

Within the overall research framework, digital survey is defined as an integrated component of information modelling and territorial analysis, supporting the development of a unified methodological system.



Chapter 5 - Architecture and Decoration: Glazed Ceramic Roof Coverings

5.1 - The Use of Ceramics as a Building and Decorative Material: From its Origins to the Present

Ceramics is one of the oldest materials employed by humankind in architecture. Derived from clay and hardened through firing, it has accompanied the development of construction techniques across almost all civilisations, progressively assuming a variety of roles: structural, decorative, and technological. The combination of aesthetic qualities and physico-chemical properties has made it a versatile and high versatile material, capable of adapting to diverse construction needs and to the different formal expressions of architecture. This adaptability is reflected in the wide range of ceramic elements found in traditional building practice: from structural components, such as bricks and blocks for load-bearing masonry, to cladding elements, including tiles and roof coverings, as well as architectural decorations and special pieces. Glazed or unglazed, ceramics thus emerges as a material capable of combining functionality and artistic value, integrating durability, modularity, and expressive potential.

In the architecture of Mesopotamian civilisations (4th-1st millennium BC), ceramics, in addition to fulfilling a functional role, held a symbolic value, representing power and sacredness. Structures built in sun-dried mud bricks (adobe) were often protected with fired and glazed bricks to improve resistance to atmospheric elements and to confer prestige upon buildings. Similarly, in Egypt (3rd-1st millennium BC), where the technique of faience developed, glazed tiles were used in sacred buildings such as temples and royal tombs.

In the Greek, Etruscan, and Roman worlds, ceramics were widely used in the form of architectural terracottas for the construction of roof coverings (tiles, *coppi*, *embrici*, acroteria, and antefixes), masonry (*opus testaceum*), cladding, and decorative elements (*opus spicatum*, floor mosaics). In particular, in Rome the use of fired brick (*opus testaceum*) marked a major construction innovation, enabling the erection of complex and durable buildings using a lightweight, manageable, and modular basic element such as

the brick.

During the Middle Ages, ceramics took on different roles depending on cultural contexts. In the Islamic world (7th-15th century), it reached a high level of technical and formal refinement, particularly in the cladding of religious buildings with glazed tiles arranged in geometric and calligraphic patterns of strong spiritual significance. In Christian Europe (11th-15th century), whereas ceramics was primarily used in the form of terracotta for floor coverings and in glazed terracottas for façades and tabernacles.

During the Renaissance (15th-16th century), ceramics once again became prominent in architectural decoration, and in Italy the use of maiolica became widespread – glazed and painted ceramics decorated with figurative and geometric motifs, employed in the cladding of floors and walls.

In the Iberian Peninsula, between the 16th and 17th centuries, the tradition of *azulejos* – glazed tiles of Islamic origin – became established, and in the Baroque period these were used to cover entire façades of religious buildings. In the Valencian region, the tradition of glazed ceramic tiles for dome coverings developed.

With the Industrial Revolution (19th century), ceramic production underwent significant transformation thanks to the introduction of modern kilns and the emergence of early industrial production, which enabled product standardisation. Ceramics thus became an economical, durable material suitable for mass construction. At the same time, the Art Nouveau movement (late 19th – early 20th century), and particularly Catalan Modernism, rediscovered ceramics as an aesthetic and plastic element.

Throughout the 20th century, with the Modern Movement (1920s-1960s), ceramics became primarily associated with functional use: tiles were extensively used for their durability, hygienic properties, and ease of maintenance, becoming typical materials for the cladding of spaces and public buildings such as schools and hospitals. From the second half of the century to the present day, technological progress has led to the development of new products such as porcelain stoneware and technical ceramics used for ventilated façades, modular cladding systems, and large-format surfaces. Today, the advent of advanced digital printing technologies and additive manufacturing further expands the potential of ceramics as an innovative and sustainable material (Figure 2).

Ceramic building elements, owing to their versatility in both historical and contemporary construction, exhibit a wide morphological variety linked to both their intended use and the specific production characteristics of different local contexts. Two features, however, remain constant: manageability and modularity. Their relatively small size allows for ease of handling during installation, enabling the simultaneous use of tools or additional construction materials. Modularity, on the other hand, governs the formation of the architectural artefact not only from a structural standpoint but also from an aesthetic and decorative perspective (Grossi, 1979). The use of glazed ceramics also provides architecture with a chromatic effect comparable to that of more precious and costly stone materials, such as marble. The ornamental design thus arises from the juxtaposition of individual elements – sometimes finely decorated in polychromy – or from the combination of monochromatic elements which, following the principles of mosaic art, generate complex geometric patterns (Figure 3).

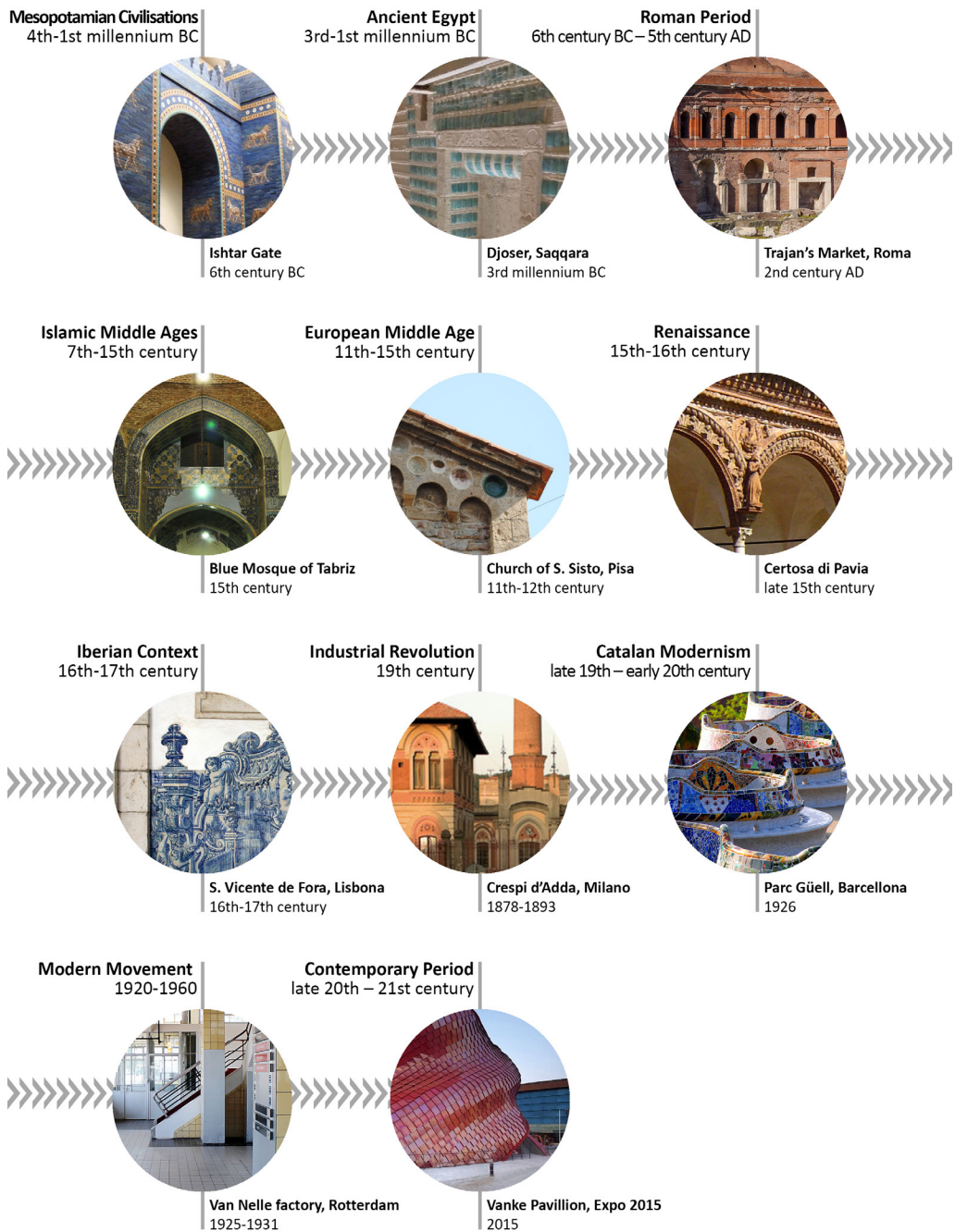


Figure 2. Timeline of ceramic architecture: chronological overview of representative examples showing the use of ceramics in architecture from antiquity to the contemporary period.



Figure 3. On the left, surfaces clad with pre-decorated polychrome maiolica tiles, arranged to form complex patterns: from top to bottom, Porta Nuova in Palermo; Capela das Almas de Santa Catarina in Porto (Portugal); installation of a traditional kitchen at the Museo de Cerámica in Manises (Valencia, Spain). On the right, cladding composed of monochromatic ceramic elements, in which the pattern derives from the arrangement of individual pieces: from top to bottom, Hôtel-Dieu in Beaune (France); bell tower of the Church of Sant'Agostino in Genoa; dome of the Church of San Michele Arcangelo in Alghero.

5.2 - The Use of Ceramics in Roofing

The use of ceramics in architectural roof coverings of different geometries represents one of the oldest and most significant applications of this material. Since antiquity, the firing of clay has made it possible to produce durable, waterproof, and standardised components, ideally suited to protecting buildings from weather conditions. Owing to their intrinsic properties of lightness, durability, and refractoriness, ceramics became the material of choice to produce tiles, crowning elements, and roof and dome coverings.

Glazed ceramic roof coverings developed in different forms depending on cultural contexts, which can be broadly grouped into four main typologies:

- Glazed curved tiles are among the most widespread elements and appear in numerous traditions, from the vibrant polychromy of Burgundian roofs to the intense blues of traditional Islamic architecture, and from the blue domes that define the skyline of the Valencian Community to the yellow tiles symbolising imperial China.
- Glazed shingles, often diamond-shaped or scale-like, were characteristic of Central Europe between the 17th and 19th centuries and proved particularly suitable for covering surfaces with variable curvature or complex geometries.
- Glazed ceramic tiles, widely used between the Renaissance and the early modern period, were employed for cladding domes, drums and lanterns structures, ensuring continuous, reflective surfaces with strong chromatic brilliance.
- Finally, glazed wedge-shaped bricks constitute a significant typological exception, used particularly in the Sicilian context for the construction of polychrome spires of towers (Figure 4).

The use of ceramic components in roof coverings is widely attested from antiquity. In Greece, from the 7th century BC onwards, the combined system of flat and curved tiles became widespread, later adopted and refined by the Etruscans and Romans in the *coppo-embrice* system, which became emblematic of Mediterranean architecture. At the same time, equally sophisticated traditions developed in the Far East: in China, as early as the Han dynasty (2nd century BC – 2nd century AD), roofs were constructed using glazed tiles, which reached their most representative form during the Ming and Qing dynasties (15th century AD), with colours linked to imperial symbolism, such as the distinctive yellow of the roofs of the Forbidden City (Gou & Wang, 2008) (Figure 5). In Japan, from the 6th century onwards, *kawara* tiles, often glazed in grey-blue tones, became a defining feature of Buddhist architecture and later of civil buildings, due to their resistance to wind and fire¹ (Figure 5).

In medieval Europe, while the use of terracotta persisted, traditions emerged in which glazed ceramics assumed a fundamental decorative role. In the Islamic world, between the 12th and 17th centuries, domes and curved surfaces were clad with blue, green, and turquoise glazed tiles, as seen in the monumental complexes of Isfahan and Samarkand, where ceramic cladding assumed strong symbolic and spiritual significance (Figure 5). In South Asia, in parallel, certain regions of India developed roofing systems based on highly resistant, low-porosity ceramic bricks, anticipating forms and tech-

¹ <https://www.makani-collective.com/story/the-evolution-of-japanese-roof-tiles>



Figure 4. Examples of ceramic roof coverings. Top left: roof covered with curved tiles, Edificio Generali, Valencia; top right: shingle roof, Monasterio San Cristóbal, Valencia; bottom left: roof clad with ceramic tiles, Church of San Giuseppe dei Padri Teatini, Palermo; bottom right: roof in wedge-shaped bricks, Basilica of Santa Caterina, Pedara (Catania).

niques that would later become consolidated in regional traditions.

In Europe, between the 14th and 15th centuries, the tradition of polychrome roofs in Burgundy emerged, characterised by flat glazed tiles in vivid colours arranged in geometric patterns (Figure 5). Between the 16th and 18th centuries, the Valencian Community introduced the use of blue glazed curved tiles for cladding domes and chapels, contributing to the definition of a highly recognisable urban landscape (Gil Saura et al., 2006) (Figure 5). In Italy, between the Renaissance and the early modern period, the use of glazed tiles and coloured roofing elements gave particular prominence to monumental roofs, especially in religious architecture, as in the cases of shingle domes in Campania (Frediani, 1996; Nicolella, 1997) and Puglia (Dell'Aquila & Favia, 1979), as well as wedge-shaped brick spires in Sicily (Fatta & Vinci, 2024; Fiorilla, 1986; Li Rosi & Russo, 2022).



Figure 5. Ceramic roof coverings. Top row, from left: Buddhist temple complex of Hōryū-ji, 6th-7th century, Ikaruga-no-Sato, Japan; Forbidden City, imperial palace of the Ming and Qing dynasties, 15th century, Beijing, China; Hôtel-Dieu, 15th century, Beaune, France. Middle row, from left: Shah Mosque, 17th century, Isfahan, Iran; Church of Santa Maria della Sanità, 1614, Naples, Italy; Basilica Nuestra Señora de los Desamparados, 17th century, Valencia, Spain. Bottom row, from left: Hungarian State Treasury Building, 1901, Budapest, Hungary; Casa Batlló, 1904-1906, Barcelona, Spain; Mercado de Santa Caterina, 2005, Barcelona, Spain.

Between the 17th and 19th centuries, ceramics continued to play a key role in roofing, but it was the Industrial Revolution that introduced standardised production processes, leading to the manufacture of pressed and glazed tiles in series, which were more uniform and durable. Within this context of innovation can be situated the roofing elements produced by the Zsolnay manufactory in Hungary between the late 19th and early 20th centuries: highly resistant polychrome tiles that characterised historicist and Art Nouveau buildings in Budapest² (Figure 5). At the same time, Catalan Modernism – particularly through the work of Gaudí – explored the use of ceramics as an ornamental cladding material, employing *trencadís* also in roofing and transforming it into dynamic and luminous surfaces (Figure 5).

In the contemporary period, ceramic roofing has undergone further development thanks to high-performance materials such as porcelain stoneware, interlocking glazed

² <https://www.meer.com/en/89571-the-lasting-impact-of-zsolnay-ceramics-in-architecture>

tiles, and laminated ceramic panels, which enable the construction of ventilated roofs, continuous surfaces, and integrated roof-façade systems. The introduction of highly resistant glazes, industrialised production processes, and large-format elements has significantly expanded the technical and application potential of ceramics, encouraging its use in contemporary architecture oriented towards durability, reduced maintenance, and the integration of envelope and roofing systems (Figure 5).

5.2.1 - Identity and Landscape: The Significance of Ceramic Roof Coverings

Glazed ceramic roofing systems constitute highly impactful landscape invariants, both due to their position along the upper profile of buildings and to the specific material and chromatic qualities of their surface layer. The reflectivity and saturation of the glaze generate distinctive features within the urban fabric, establishing themselves as orientation devices and markers of local identity.

Since antiquity, different cultures have attributed to glazed roof coverings not only a functional role but also a symbolic one: the turquoise domes of Islamic architecture, the yellow tiles of imperial China, and the blue domes of the Valencian tradition represent examples in which colour becomes a recognisable device and a generator of identity. Similarly, in the modern period, the glazed roofing produced by the Zsolnay manufactory in Budapest and the ceramic experiments of Catalan Modernism consolidated the use of glazed cladding as an element capable of distinctly characterising the urban landscape.

From the perspective of spatial perception, ceramic roof coverings fulfil functions that can be interpreted through the theoretical categories developed by Kevin Lynch (Lynch, 1964). By virtue of their elevated position and material distinctiveness, they operate as landmarks (visual references): point elements which, emerging from the continuous built fabric, facilitate orientation and contribute to the construction of the “image of the city”. The chromatic intensity and reflectivity of the glaze enhance their legibility, transforming them into mnemonic nodes that reinforce the sense of identity and the persistence of places within the mental map of inhabitants. At the same time, the approach proposed by Gordon Cullen in *Townscape* (Cullen, 1961) allows glazed roof coverings to be interpreted as devices that affect the perceptual sequence of space: they act as focal points and scenographic “moments” that structure the urban sequence. Their capacity to reflect light and to change with atmospheric conditions introduces a dynamic component into the landscape, contributing to that “visual plasticity” which Cullen identifies as one of the fundamental elements of the aesthetic experience of the city.

For people, such roof coverings therefore represent visual and cultural markers capable of activating processes of identification and symbolic continuity. Even in contexts characterised by rapid transformation, the persistence of glazed roof coverings reinforces the perception of stability and rootedness, configuring them as key elements in the construction of the urban landscape and in defining the character of places.

5.3 - The Ceramic Production Cycle: Materials, Techniques, and Production Environments

The production of ceramic artefacts consists of a sequence of technical phases which, although presenting local variations related to the availability of raw materials, artisanal traditions, and the functional requirements of the products, are broadly shared across different geographical and chronological contexts. These phases do not necessarily take place in a single location or within a continuous timeframe, but may instead be distributed spatially and temporally, involving specialised workers, each responsible for specific stages of the production process.

From the extraction of raw material to the production of the finished object, the production cycle may therefore include activities carried out by different operators – from the procurement and preparation of raw materials to shaping and finally firing and finishing – according to an organisation of labour that varies depending on the economic and productive context. Each stage has a decisive impact on the physical, mechanical, and aesthetic properties of ceramics, also influencing their durability and long-term performance.

This section provides a general overview of the main phases of ceramic production, as well as the spaces and tools associated with them, in order to establish a reference framework for understanding the specific characteristics of the production centres analysed in the following chapters. The primary references for this description are Clark (1988) and Volante and Giannichedda (2007).

The ceramic production cycle takes place within a spatial system that are functionally distinct yet closely interconnected, whose organisation reflects both the technical requirements of the different stages of production and the availability of natural resources. The extraction of raw materials, preparation of the clay body, shaping, drying, firing, and glazing require environments with different spatial characteristics and microclimatic conditions. In many production contexts, these activities are concentrated within a single complex, whereas in others they are distributed across the territory according to the location of resources, particularly clay deposits, water availability, and woodland areas necessary for fuel supply. This organisation may result in a physical separation between extraction areas and production sites, or in a greater integration of the different stages of the process.

The spaces dedicated to the preparation of the clay body and shaping are generally located near one another to ensure operational continuity, while drying areas and kilns are arranged according to a functional sequence that allows the progressive advancement of artefacts along the production cycle. This arrangement responds not only to efficiency criteria but also to the need to control timing and environmental conditions.

The organisation of production spaces is also closely linked to the division of labour, which may involve specialised workers with differentiated skills or be concentrated within a limited number of operators, depending on the scale and level of specialisation of production. In all cases, the spatial configuration of production sites represents a key factor in understanding operational practices, the quality of products, and the relationship between ceramic production and the territorial context.

Within this complex system of spaces, the production process begins with the sourcing of raw materials, primarily clay and water, both essential resources for transforming raw material into ceramic artefacts. Clay, of sedimentary origin, is generally extracted from open-pit quarries or collected from alluvial deposits, often located near water-courses in areas easily accessible from production sites.

The selection of clay is based on a series of empirically recognised factors, including plasticity, workability, and the presence of inclusions or impurities such as carbonates, oxides, or organic materials. These characteristics directly influence the behaviour of the clay body in the subsequent stages of the production process, affecting dimensional stability, porosity, and the mechanical performance of the artefacts. In some contexts, the extracted material is also subjected to a weathering phase, during which the clay is left to rest for varying periods, promoting its natural disaggregation and improving its homogeneity and physical properties prior to processing.

Alongside clay, water represents a fundamental resource throughout the entire production cycle. It is required not only to impart plasticity and mouldability to the clay body, through the formation of stable colloidal suspensions, but also for a range of auxiliary operations essential to ceramic production. Water is used in the preparation and dilution of pigments and glazing mixtures, as well as for functional and domestic uses within the kiln and working areas. The availability of water resources therefore constitutes a determining factor in the location of ceramic production sites, which are frequently situated near rivers, springs, or water supply systems capable of ensuring continuity throughout the various stages of the production process.

Once procured, the clay material undergoes a preparation phase aimed at making it suitable for shaping. This phase includes a series of operations intended to remove impurities, regulate the granulometric composition of the material, and obtain a homogeneous clay body with physical properties appropriate for subsequent processing.

The clay is initially crushed and disaggregated, either manually or with simple tools, and then mixed with water until a plastic and workable consistency is achieved. The amount of water used plays a crucial role in determining the rheological behaviour of the clay body, affecting both its workability and the dimensional stability of the artefact during drying and firing.

In the case of excessively plastic clays, the mixture may become unstable and prone to deformation or cracking; to address these issues, so-called tempering agents or degreasers are added, such as sand, chamotte³, mineral aggregates, or, in some production contexts, finely chopped plant remains. The addition of these components increases the consistency of the mixture, improves the permeability of the material, and reduces shrinkage during drying and firing. Conversely, in the case of poorly plastic clays, mouldability can be improved by modifying the composition of the material through the removal of non-clayey particles. This process may take place through decantation in water, sometimes over extended periods, and/or through sieving, which allows materi-

³ Chamotte is a term of French origin, widely used in ceramic technical vocabulary, referring to ceramic material obtained from the crushing of previously fired clay artefacts, used as a tempering agent in ceramic bodies to improve dimensional stability and reduce shrinkage and cracking during drying and firing.

als to be separated according to size and specific weight, distinguishing between coarse and fine fractions and eliminating those unsuitable for ceramic processing.

Mixing and homogenisation operations may take place in tanks, basins, or specially prepared surfaces, using techniques ranging from simple manual kneading to the use of mills or mechanically operated tools. These operations are carried out within dedicated working spaces, often covered but open laterally, in order to ensure controlled environmental conditions and an efficient connection with the subsequent stages of the production cycle. The outcome of this phase is a uniform plastic material, ready to be shaped into the desired form through various forming techniques.

The forming stage represents the moment in which the prepared clay body is transformed into the actual artefact. It consists in shaping the plastic material into predetermined forms and dimensions through techniques that vary according to the type of object to be produced, the level of specialisation of production, and the degree of standardisation required. Forming is carried out in spaces specifically designated for this phase of the production process, generally located in proximity to the areas for clay preparation and organised according to the type and quantity of artefacts to be produced.

Forming techniques may vary and include manual modelling, the use of moulds or templates, and wheel-throwing. In the case of ceramic elements intended for architecture, and in particular for roofing, production tends to favour techniques that ensure repeatability and dimensional uniformity, conditions that are essential for proper installation and the correct functioning of the roofing system. The use of moulds, made of wood, plaster, or ceramic material, makes it possible to obtain elements with consistent morphological characteristics and to reduce production time. This approach is particularly suited to the manufacture of serial elements such as roof tiles and other modular components, while the wheel is mainly used for producing axially developed artefacts or specialised decorative elements.

During forming, particular attention is paid to the thickness of the artefacts and the regularity of their surfaces, aspects that directly affect the behaviour of the material during the subsequent stages of drying and firing. Irregularities or inhomogeneities may lead to deformation, internal stresses, or structural defects, thereby compromising the quality of the final product.

At the end of the forming stage, the artefacts are finished through smoothing and edge regularisation, and then transferred to the drying areas, following a functional sequence that reflects the overall organisation of the production site.

The drying stage follows forming and aims to progressively remove the water contained in the clay body, allowing the artefacts to acquire sufficient strength to undergo firing. This is a crucial step in the production cycle, as uncontrolled drying may irreversibly compromise the quality of the final product. During this phase, the gradual loss of water leads the material from the stage commonly referred to as 'green clay' to that of 'leather-hard', corresponding to an artefact that is now dried, dimensionally stable, but not yet fired.

Drying generally occurs naturally, through exposure of the artefacts to air in protected yet well-ventilated environments. These spaces are often covered, to protect the piec-

es from direct solar radiation and precipitation, but open on the sides to allow slow and uniform evaporation of residual moisture. The duration of this phase varies according to climatic conditions, seasonality, and the dimensional and morphological characteristics of the artefacts.

During drying, particular attention is paid to controlling volumetric changes in the material, related to clay shrinkage following water loss. Excessively rapid or uneven shrinkage may result in cracking, deformation, or internal stresses, which tend to be more evident in larger elements or those with irregular thicknesses. To minimise these risks, the artefacts are placed on flat surfaces, racks, or dedicated supports, ensuring adequate air circulation and reducing contact points. In some cases, drying may be carried out progressively by moving the pieces between spaces with different microclimatic conditions, until a moisture content suitable for firing is achieved.

At the end of the drying stage, the artefacts have sufficient consistency to be handled and loaded into the kiln, thus entering the firing phase.

The firing stage represents the most delicate and irreversible phase of the entire ceramic production cycle, as through the action of heat the artefact undergoes a permanent physico-chemical transformation that determines its mechanical properties, porosity, strength, and long-term durability. Through firing, the object passes from the state of dried material to that of ceramic proper, acquiring structural stability and compactness.

The firing process takes place within purpose-built kilns and involves reaching temperatures generally ranging, depending on the type of clay body and artefact, between approximately 700°C and 1000 °C, with lower values for common ceramics and higher ones for materials intended to ensure greater mechanical performance and resistance to atmospheric elements. Control of temperature and residence time within the kiln is therefore crucial to the final quality of the product.

From a typological perspective, kilns used for ceramic production can be classified into different models. An elementary form is the clamp-type kiln, built in the open air or within pits excavated in the ground, in which artefacts are placed in direct contact with the fuel. These structures are sometimes covered with earth or vegetal materials; however, they do not allow precise control of temperature or firing atmosphere. A significant technological development is represented by two-chamber kilns, in which the combustion chamber and the firing chamber are separated by a perforated partition. In this system, artefacts placed in the firing chamber – generally located above (vertical kilns) or adjacent to (horizontal kilns) the combustion chamber – are exposed to heat and flue gases without coming into direct contact with the flame, allowing for a more orderly arrangement of the pieces and improved process control. A further level of control is achieved in muffle kilns, characterised by enclosed firing chambers in which the artefacts are not directly exposed to combustion gases. Heating occurs externally to the firing chamber, ensuring greater thermal uniformity and better protection of surfaces, which is particularly important for glazed or decorated artefacts.

During firing, a series of progressive transformations occur, including the removal of residual water, the combustion of organic substances, the decomposition of carbonates,

and, at higher temperatures, sintering⁴, which gives the material greater compactness and strength. These transformations are followed by a gradual cooling phase, during which the artefacts remain inside the kiln until thermal conditions suitable for their removal are reached, thereby avoiding thermal shock and cracking.

The operation of traditional kilns is closely linked to the availability of fuel, historically consisting mainly of firewood. The presence of woodland areas near ceramic production sites has therefore been a determining factor in the location of kilns, directly influencing territorial organisation and the long-term sustainability of production activities.

Glazing constitutes a specific phase of the ceramic production cycle, aimed at applying a surface coating capable of modifying and enhancing both the functional and aesthetic characteristics of the artefact. In the case of ceramic elements intended for architecture, and in particular for roofing, this treatment plays a fundamental role, as it significantly reduces surface porosity, improving resistance to water absorption and prolonged exposure to weather conditions.

Slip (*ingobbio*) is a coating consisting of a suspension of finely refined clay, applied to the surface of the artefact in its unfired or leather-hard state, primarily to homogenise and prepare the surface, also in view of the possible application of vitreous coatings.

Transparent vitreous coatings, commonly referred to as glazes, are obtained through the application of silica-based mixtures, in which quartz, combined with fluxes, melts during firing to form a continuous and impermeable glassy layer. Glaze protects the ceramic surface by reducing its porosity while allowing the colour of the clay body or the underlying slip to remain visible. When an opacifier, such as tin dioxide, is intentionally added to the silica-based mixture, an opaque glaze is produced, characterised by a uniform light-coloured appearance capable of masking the colour of the ceramic body. The presence of fluxes, often lead-based, promotes melting and gives the surface a smooth and glossy finish. This type of coating requires careful control of both composition and firing cycle to ensure compatibility between glaze and substrate.

The addition of metallic oxides to vitreous mixtures allows for the production of coloured glazes, imparting specific chromatic qualities without altering their protective function.

The application of slip and glazes is closely linked to the firing stage. The coating may be fixed through a second firing, following the initial firing of the ceramic body, or through a single firing, in which body and coating mature simultaneously. In both cases, achieving appropriate temperatures is essential to ensure that the coating melts correctly, adheres to the substrate, and develops the desired properties of impermeability and resistance.

An improper balance between clay body, coating, and firing cycle may lead to incompatibility phenomena such as crazing, detachment, or surface stresses, which over

⁴ Sintering is a process that, at high firing temperatures, leads to the progressive cohesion of the ceramic body particles without complete melting, increasing the compactness and strength of the material.

time compromise the protective effectiveness of the glaze. These aspects are particularly relevant in roofing elements, for which the continuity and stability of the surface coating are essential requirements for the durability of the system.

The overall framework of the production process outlined in this section provides the interpretative tools necessary both for the analysis of ceramic production centres and for understanding the deterioration phenomena affecting architectural artefacts, which will be examined in the following chapters.

5.4 - Deterioration of Architectural Ceramics

Like any handcrafted product, ceramic artefacts may undergo deterioration processes that lead to the decay of their physical and chemical properties, altering their ability to meet the required functional and aesthetic performance. In the case of ceramic elements used in architecture, the typical causes of deterioration affecting ceramics are compounded by those affecting building materials, which are exposed to atmospheric elements and subject to wear resulting from use. It is therefore essential to emphasise that, for a correct diagnosis of deterioration causes and for subsequent conservation and restoration interventions, individual ceramic elements should not be considered in isolation but rather as part of the architectural system formed by their assembly (Fabbri, 2003). Furthermore, in cases where ceramic elements also perform structural functions (such as bricks and wedge-shaped bricks), it is necessary to identify cracking patterns, investigate the causes of structural distress, and assess the structural behaviour of the construction to prioritise structural safety.

The deterioration of ceramic artefacts can be attributed to physical, chemical, or biological actions. It should be noted that multiple deterioration processes may occur simultaneously within a single artefact and, moreover, that actions of a given nature – physical, chemical, or biological – may trigger reactions belonging to another category. Furthermore, deterioration can be attributed to two main categories of causes: intrinsic and extrinsic (Fabbri, 2004).

The former are related to the production phase of the elements and, consequently, to the composition of the clay body, firing temperatures and durations, and the application of vitreous coatings. When the amount of non-plastic inclusions is insufficient to compensate for shrinkage during drying, fractures and cracks may develop; moreover, the presence of impurities and salts may trigger both physical and chemical deterioration processes. Calcium carbonate nodules and relics of clay minerals present within inadequately fired bodies, due to their volumetric expansion upon hydration, may lead to the formation of small craters in the ceramic body or protuberances in the glaze layer. The most frequent defects associated with the application of vitreous coatings are shrinkage-related and are caused by differential contraction between the ceramic body and the glaze: the latter may undergo tensile stress, resulting in crazing, if it contracts more than the ceramic body, or compressive stress, resulting in flaking, if the ceramic body contracts more. Furthermore, if carbon dioxide generated during firing is unable to escape to the surface, gas bubbles may form, producing pinholes in the glaze or remaining trapped within it. The interface between the ceramic body and the glaze is the most

sensitive zone, as it may facilitate water ingress and thus trigger further deterioration mechanisms; good adhesion between the two is therefore a fundamental requirement for ensuring the durability of the artefact (Vendrell-Saz, 2003).

Extrinsic causes are related to the interaction between the environment and the artefact, as well as between humans and the artefact, and may involve physical, chemical, or biological actions.

Physical actions produce mechanical stresses on the artefact. Water can generate two types of mechanical stress: those resulting from the expansion and contraction of water particles within the material due to phase changes, and those caused by water flow over the surface of the artefact. In the former case, stresses generated by freeze-thaw cycles often lead to material disintegration; in the latter, water and the solid particles it carries exert an erosive action on the artefact. Soluble salts present in ceramic materials – either transported by water or originally contained as impurities in the unfired clay – migrate from the core towards the surface through pores and microcracks, generating pressures due to repeated cycles of dissolution and crystallisation, which may induce phenomena such as decohesion, exfoliation, and powdering of the body, as well as detachment of surface coatings. Ceramic elements used in architecture are particularly susceptible to moisture-related deterioration, due both to the action of water and to the inherently high porosity of ceramic materials. Variations in relative humidity produce cycles of wetting and drying that stress the material, leading to its disintegration and facilitating further water infiltration. These phenomena may be caused by construction moisture, when moisture originates from building components (for example, mortar with excessive water content), or by external moisture sources, such as rising damp, penetrating damp, or condensation. Moisture-related deterioration may manifest through efflorescence and sub-efflorescence caused by soluble salts, disintegration phenomena due to volumetric expansion of salts and water particles, and the appearance of stains. The low coefficient of thermal expansion of ceramics makes them susceptible to damage induced by environmental temperature variations, whether on a daily (day-night) or seasonal (summer-winter) basis, leading to cracking, fracturing, and detachment, particularly where embedded metal elements are present. Moreover, differences in thermal expansion coefficients between the ceramic body and the glaze result in differential behaviour between the two. Wind, which carries airborne particles, is another cause of deterioration, as it exerts an abrasive action on surfaces and acts as a transport medium for salts and pollutants that deposit on them. The application of loads exceeding the mechanical resistance of ceramic materials may generate compressive, bending, and shear stresses incompatible with the brittle behaviour of ceramics, resulting in cracks and fractures. Finally, considering that ceramic materials are often used for flooring, deterioration caused by wear due to foot traffic must also be taken into account.

Chemical actions may be caused by natural agents (water, carbon dioxide, acids, etc.) or by human activities (fires, environmental pollution, inappropriate restoration interventions, etc.). The porous structure of ceramics favours the absorption of significant amounts of water from the environment, promoting the phenomenon of rehydration (reclaying), which – especially in the presence of high porosity and insufficient firing – renders ceramic objects softer and more fragile and may lead to deformation (Cavari,

2007). Soluble salts may chemically react with the ceramic material, altering its composition; salt crystallisation, identifiable through the presence of a white powdery phase, may occur on the surface (efflorescence) or within the ceramic body (sub-efflorescence), causing exfoliation and detachment of surface layers. Certain salts may also lead to devitrification of the glaze. Substances such as calcium carbonate, chlorides, nitrates, and sulphates, transported by water or air and deposited on ceramic artefacts, may give rise to leaching processes, through which certain chemical components are removed from the ceramic body. Furthermore, the deposition of such altering substances, often generated by atmospheric pollution, may lead to the formation of new surface layers, such as gypsum crusts composed of insoluble carbonate and silicate particles. The presence of metallic elements, which are prone to oxidation – especially when exposed to atmospheric elements – results in the formation of staining and runoff marks. Ultraviolet radiation may induce photochemical reactions in organic materials and, in the case of ceramic artefacts, may alter decorative pigments.

Biological actions, caused by living organisms, produce effects that can be attributed to both physical and chemical deterioration processes. Algae, fungi, lichens, and mosses – microorganisms whose growth is favoured by the presence of water and which feed on inorganic substrates – may lead to the formation of acids that, as previously noted, corrode the ceramic body or its surface. Plant roots may attack ceramic elements, causing mechanical damage such as cracking, breakage, and detachment, thereby compromising their integrity. Finally, the accumulation of guano on the surface of ceramic elements, due to its high nitric acid content, may cause chemical deterioration.

Human intervention in restoration processes has not always been appropriate, particularly in the past, leading to further damage. This may result, for example, from the use of materials and substances incompatible with the ceramic substrate, the introduction of soluble salts during cleaning operations, or incorrect repositioning and reintegration, which in some cases have caused the loss of information about the artefact.

Table 4. Explanatory table showing the relationships between the causes of deterioration, the visible manifestations of these causes, and the architectural elements of ceramic materials.

CAUSES OF DETERIORATION		VISIBLE MANIFESTATIONS	Architectonical elements				
			structural elements	cladding elements			
				floors	walls	roofs	
INTRINSIC	Insufficient non-plastic inclusions	Fractures and cracks	•	•	•	•	
	Insufficient firing temperature and duration	Craters and protuberances	•	•	•	•	
	Incorrect application and/or firing of the glaze	Crazing and flaking		•	•	•	
EXTRINSIC	PHYSICAL ACTIONS	Water	Disintegration and erosion	•	•	•	•
		Soluble salts	Exfoliation and detachment of the coating	•	•	•	•
		Humidity	Disintegration	•	•	•	•
		Temperature variations	Cracks, fractures, and detachment	•	•	•	•
		Wind exposure	Corrosion	Se a vista		•	•
		Excessive loads	Cracks and fractures	•	•		
		Wear	Erosion and thickness reduction		•		
	CHEMICAL ACTIONS	Water	Rehydration of clay minerals and chromatic alteration	•	•	•	•
		Soluble salts	Efflorescence, sub-efflorescence, and detachment	•	•	•	•
		Acids and other substances	Leaching, encrustations, and crust formation	•	•	•	•
		Ultraviolet radiation	Chromatic alteration		•	•	•
	BIOLOGICAL ACTIONS	Algae, fungi, lichens, and mosses	Disintegration and corrosion	•	•	•	•
		Vegetation	Cracks, fractures, and detachment	•	•	•	•
		Guano (nitric acid)	Corrosion and chromatic alteration		•	•	•



Chapter 6 - Architecture and Landscape Between Sicilian Spires and Valencian Domes

The investigation focuses on two case studies in which glazed ceramics have played a defining role in shaping the urban and territorial image: the spires of Sicilian bell towers, clad with glazed wedge-shaped bricks, and the domes of the Valencian Community, characterised by glazed roof tiles. In both contexts, the use of ceramics in roofing becomes a defining feature of the skyline, responding not only to functional and construction requirements: their elevated position, the use of colour, and the material's responsiveness to light determine their perception within the landscape. This widespread use is supported by a long-standing production tradition that, in both regions, has favoured the adoption of ceramics as the material of choice for monumental roofing.

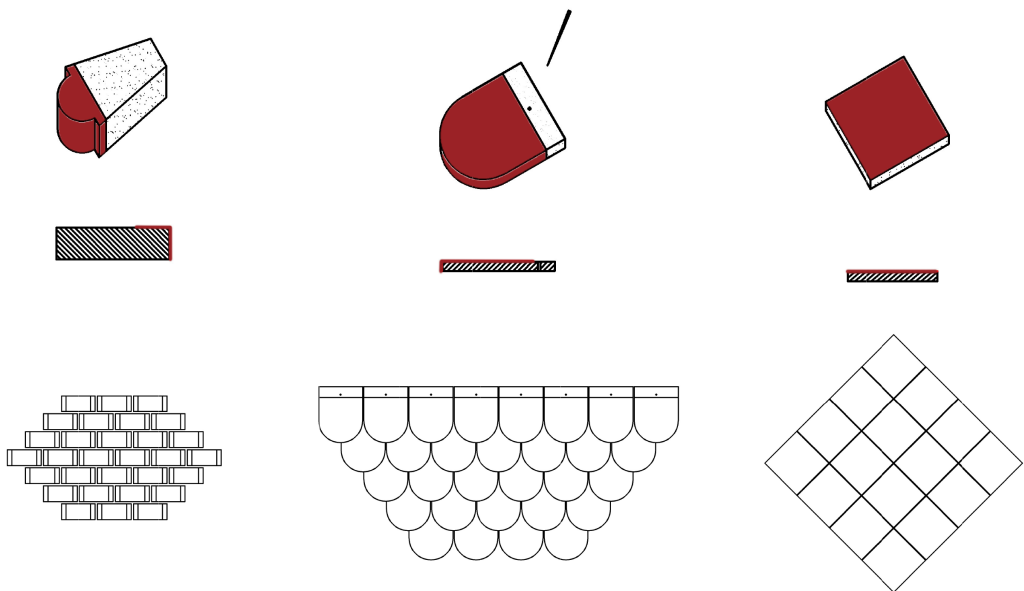


Figure 6. Three main categories of ceramic elements for Sicilian roofing: wedge-shaped bricks, shingles, and ceramic tiles.

◀ Spire of the Church of Santa Maria Maggiore in Geraci Siculo (PA).

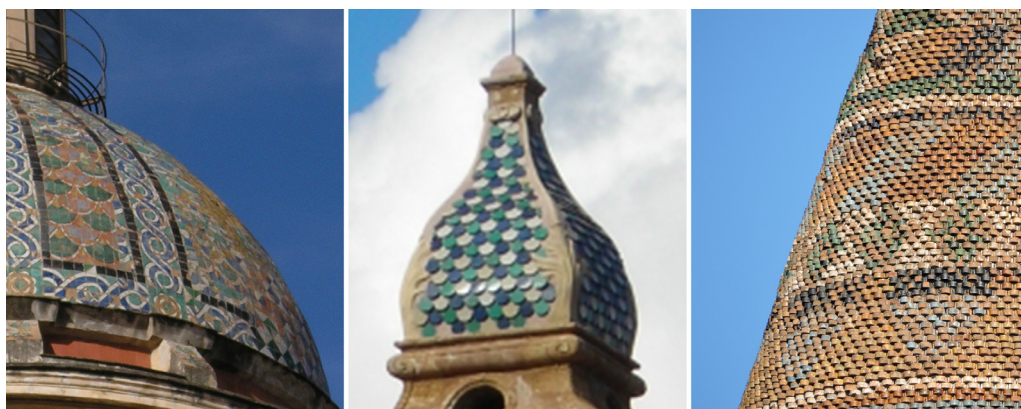


Figure 7. Examples of Sicilian ceramic roof coverings. From left: dome of the Church of Carmine Maggiore, Palermo, 17th century, clad with *maduni*; spire of the bell tower of the Church of the Santissimo Crocifisso in Castelbuono (PA), clad with shingles; spire of the south bell tower of the Basilica Cattedrale Maria Ss. Annunziata, Acireale (CT), structural cladding in wedge-shaped bricks.

Within this tradition in Sicily, it is possible to identify three main categories of ceramic elements used in roofing – ceramic tiles, shingles, and wedge-shaped bricks – each characterised by specific morphological, technical, and installation features (Figure 6).

Ceramic tiles, known locally as *maduni*, are used as cladding for roofs with planar slopes or domes. Typically square or hexagonal in shape, they are installed using a bedding mortar applied to the underlying surface, and the decorative pattern may derive either from the combination of tiles of different colours arranged according to geometric schemes or from the juxtaposition of decorated tiles to form a design (Figure 7). Shingles – or scales – are flat elements generally used for cladding domes. They are partially glazed, only on the upper surface, leaving unglazed the portion overlapped by the shingles of the subsequent layer; they are fixed using bedding mortar and a nail. The decorative pattern is obtained through the arrangement of monochromatic elements (Figure 7). Wedge-shaped bricks are characterised by a glazed curved or polygonal head and a longitudinal tapering, and are typically used as cladding for spires, pinnacles, and finials (Figure 7).

In the Valencian context, glazed ceramics find one of their most emblematic architectural expressions in roof coverings made with tiles, particularly glazed curved roof tiles and, in later periods, shingles (Figure 8). These coverings are not limited to large domes defining the urban skyline, but also include smaller-scale elements such as cupolas, lanterns, spires, and secondary crowning elements. The association between glazed ceramics and blue colour schemes – often combined with white – contributes to making these architectural features a distinctive and immediately recognisable element of Valencian architecture, both in urban settings and in the surrounding territory.

The chapter is structured according to a parallel approach for the two contexts analysed. For each case, the following aspects are examined: ceramic production frameworks, territorial distribution of roof coverings, perceptual aspects, and material and construction characteristics. Decorative systems and the main deterioration phenomena are also investigated. This structure enables a comparative reading that highlights –



Figure 8. Examples of Valencian ceramic roof coverings. Left: dome of the Iglesia del Temple, Valencia, 18th century, covered with roof tiles. Right: dome of the Iglesia de Nuestra Señora del Puig, Valencia, 19th century.

despite the different technical and formal solutions – how ceramic roofing plays, in both contexts, a central role in the relationship between artisanal production, architecture, and the image of the built landscape.

6.1 - Glazed Wedge-Shaped Brick Roof Coverings in Sicily

In Sicily, there is a significant heritage of bell towers with spires clad in – or entirely constructed from – wedge-shaped bricks in maiolica. These spires rise as crowning elements with varying geometries that enhance their visibility. In addition to their form, they are often distinguished by their surface finishes, characterised by the use of polychrome maiolica with geometric patterns, which produce a strong visual impact and define the skyline of the settlements in which they are located.

In this regard, it is important to note that similar structures, characterised using shaped brick elements for the construction of conical or pyramidal roof forms, are also documented in other areas of Italy. In such cases, however, the bricks are generally left exposed, without glazed coating, and therefore assume a primarily constructive rather than decorative role. There are also occasional examples in which such coverings include glazed ceramic elements; however, these remain isolated cases, not attributable to an established tradition or to a systematic territorial diffusion (Figure 9). In this sense, the Sicilian context stands out for the extensive and intentional use of glazing, which plays a decisive role in defining both the architectural image and the landscape value of these spires.

The study conducted on these architectural elements has, to date, identified approximately one hundred spires in Sicily featuring glazed ceramic elements in their roofing. Of these, ninety employ elements known as wedge-shaped bricks – also referred to as



Figure 9. Examples of wedge-shaped brick spires in Italy. From left: Waldensian Evangelical Church of Verona; Cathedral of Santa Maria Assunta, Verona; Church of Santa Maria del Popolo, Rome; Church of Santa Maria dell'Anima, Rome.

bugnette or *zoccoli* – while the remainder use ceramic tiles or shingles (also known as *squame* or *embrici*). These structures, dating in most cases to the period between the 17th and 18th centuries, are primarily concentrated in municipalities located in inland areas and in proximity to major ceramic production centres, including Burgio, Caltagirone, Santo Stefano di Camastra, Naso, Collesano, and Gangi.

The earliest documented evidence of the supply of wedge-shaped bricks for the construction of a spire in Sicily dates back to 1579 and concerns the Church of San Giacomo in Collesano (Termotto, 2005, p. 450). The most recent example appears to be the church of Borgo Giuliano, a rural settlement in the territory of San Teodoro (ME), built by 1940 and currently in a state of ruin. In this case, the reinforced concrete spire of the bell tower and the semi-domes of the lateral chapels are clad with glazed wedge-shaped bricks produced in Santo Stefano di Camastra (Sapienza, 2010, p. 104).

Within this framework, before examining the territorial distribution of spires and their associated construction techniques, it is appropriate to recall the context of ceramic production in Sicily, with particular reference to glazed elements intended for this type of roofing.

6.1.1 - History and Techniques of Sicilian Ceramic Production

The history of ceramics in Sicily dates back to the 5th-4th millennium BC, with the production of everyday objects hand-modelled by the island's earliest communities, using simple clay bodies and basic decorative schemes. During the Bronze and Iron Ages (2nd-1st millennium BC), local production underwent an initial technical development thanks to contacts with other Mediterranean cultures; later, with Greek colonisation, the introduction of the potter's wheel, kilns, and glazing techniques led to the establishment of workshops in the major Hellenic centres of the island around the 5th-4th century

BC¹. During the Roman period, production activity continued to develop, particularly through the manufacture of transport amphorae and cooking ware; an important production centre in this period was Centuripe (Ragona, 1955, pp. 5-6).

In the late antique and Byzantine period (5th-9th century), ceramic production experienced a phase of decline due to fiscal policies and to devastation caused by vandal incursions and piracy; glazing techniques were lost, and both clay bodies and forms became simplified (Ragona, 1955, pp. 5-6).

A renewed phase of innovation arrived with Arab domination between the 9th and 11th centuries. Continuous commercial exchanges between Sicily and North Africa enabled the circulation of people and goods, leading to the introduction of new techniques – maiolica, lead-based glazes, glazing processes, and metallic lustres – as well as new decorative repertoires. Islamic ceramic traditions continued to develop on the island during the Norman and Swabian periods (11th-13th centuries), supported by the trade agreements promoted by Federico II in 1231, and subsequently, following the fall of the Swabians, under Angevin rule from 1270 onwards. The prosperity of ceramic production during this period is also evidenced by the taxes paid by artisans for the exercise of their activity, such as the *cabella figulorum*, the tithes of the *jus celamidae*, the *cabella dohane*, or the 5% duty “de omnj opere crete et vitri extracto per mercatores exteros” (D’Angelo, 2010, p. 108; Daidone, 2005, p. 14; Ragona, 1955, pp. 6, 10-22).

Between the late 13th and early 14th centuries, the War of the Sicilian Vespers led to the division of the island into *pars latina*, associated with the Swabian and Angevin factions and predominant in western Sicily, and *pars catalana*, linked to the new Aragonese rule and present in eastern Sicily. Within this context, Moorish influences were complemented by Spanish ones, particularly through maiolica known as *di mursia* or *di valenza* (Daidone, 2005, pp. 15-16; Ragona, 1955, pp. 6-8). During this period, Sicily not only produced ceramics for internal use but also exported goods to Spain, referred to as *operis de Cicilia*. Documentary sources also record taxes paid by artisans and, in Palermo, among the craft guilds offering candles in liturgical celebrations, the presence of the *Quartarariorum* – that is, potters – testifies to their importance (Ragona, 1955, pp. 23, 25). Towards the end of the 15th century and the beginning of the 16th, the closure of several kilns reflects a decline in ceramic production, largely due to competition from Valencian and Italian Renaissance ceramics (Ragona, 1955, pp. 27, 29).

In the 16th century, Renaissance ceramics influenced local production, leading to the emergence of major Sicilian ceramic centres – including Caltagirone, Sciacca, and Palermo. Sicilian workshops attempted to follow prevailing stylistic trends, although only Palermo managed to approach the excellence of contemporary Italian production. From the 16th century onwards, production in Sciacca was influenced by Savona traditions, while the workshops of Caltagirone – geographically more distant from maritime trade routes – remained anchored to local Hispano-Moorish traditions until the late 17th century (Daidone, 2005, p. 18; Ragona, 1955, pp. 8, 30, 33; Reginella, 2003, p. 9). During this period, the movement of artisans – both from major Italian ceramic centres such

¹ Finds have been recorded at Riesi, Mazzarino, Syracuse, Megara Iblea, Caltagirone, Centuripe, and Mozia (Ragona, 1955, p. 5).

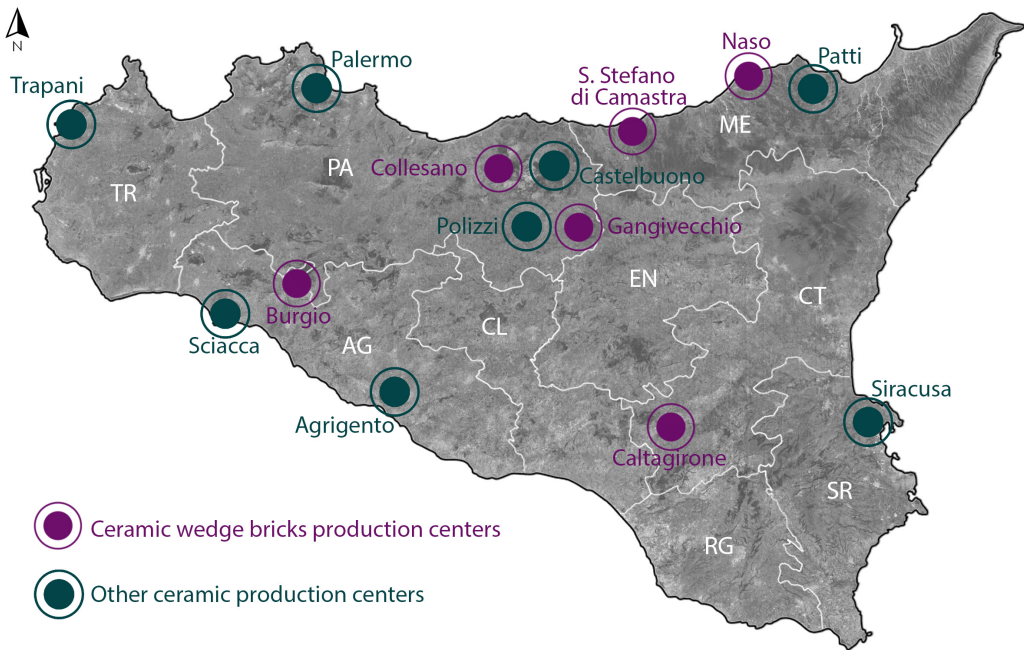


Figure 10. Mapping of the main ceramic production centres. In purple are highlighted those centres where the specialised manufacture of wedge-shaped bricks for the construction of spires is documented.

as Liguria, Faenza, Urbino, and Venice, and within Sicily itself among active production centres (Caltagirone, Burgio, Sciacca, Naso, Palermo, Collesano, Polizzi) – contributed to stylistic influences and to the prominence of Palermo, Caltagirone, and Sciacca (Daidone, 2005, p. 18).

From the second half of the 18th century, many workshops across the island began to disappear, except for those in Caltagirone and the more recent ones in Santo Stefano di Camastra, which have remained active to the present day (Ragona, 1955, p. 8).

In the 20th century, after a period of decline caused by the spread of standardised industrial products, Sicilian ceramics experienced renewed interest, combining the recovery of tradition, artistic experimentation, and semi-industrial production. An important role was played by scholars who contributed through their research on the history of ceramics on the island – including Paolo Orsi, Antonio Salinas, Enrico Mauceri, Guido Russo Perez, and Antonino Ragona (Fiorilla, 1991) – as well as by museums, which promoted the valorisation and dissemination of this artistic heritage, and by art institutes, which trained new generations of ceramicists (Reginella, 2015a).

In light of the chronological overview outlined above, the discussion will focus exclusively on those production centres for which the manufacture of wedge-shaped bricks is documented through material and documentary sources – namely Caltagirone, Burgio, Collesano, Naso, Santo Stefano di Camastra, and Gangi – excluding contexts where such evidence is lacking (Figure 10).

Caltagirone

The ceramic tradition of Caltagirone (province of Catania) represents one of the

most significant cases within the Sicilian production landscape, due to its historical continuity, the scale of its production, and the influence it exerted on other centres across the island. This tradition most likely dates to the period of Arab domination in Sicily, although some scholars argue that the Arabs developed a pre-existing local tradition. Artisans enjoyed a degree of autonomy that allowed them to continue their activities for a long time in this area, which was rich in clay deposits and woodlands providing fuel for kilns. Evidence of this is found in archaeological excavations carried out in the early 18th century, during which workshops of *cannatari*² were discovered at depth, buried by a landslide in the Muslim quarter in 1346. Subsequently, in 1764, remains of kilns were uncovered beneath the Church of San Giacomo, built in 1090 (Ragona, 1955, pp. 43-45).

Although some workshops survived the landslide of 1346, most were rebuilt to the south of the city, near the Church of San Giuliano and the Jewish quarter, in the district that took its name from this activity – Cannataria. By contrast, the workshops of the *quartarari*³ and the *stazzunari*⁴ were located outside the urban centre, from Porta del Vento to the Church of San Giovanni dei Cavalieri di Malta (Fiorilla, 1992, p. 29; Ragona, 1955, p. 46; Reginella, 2003, p. 19).

In the 15th century, the importation of Hispano-Moorish ceramics led to a significant revival of production activities, and Caltagirone obtained recognition of civic rights to the woodland of San Pietro, part of the municipal domain, which allowed artisans to freely collect firewood for kiln use. Furthermore, the granting of the fair of San Giacomo contributed to the expansion of commercial exchanges (Reginella, 2003, p. 16).

In the 16th century, ceramic production in Caltagirone still displayed decorative motifs and manufacturing processes of Arab and Spanish origin. One of the main fields of specialisation during this period was the production of maiolica floor coverings, also benefiting from the presence of craftsmen from other parts of Italy, who were already working in a Renaissance style (Ragona, 1955, p. 48; Reginella, 2003, p. 19).

In the 17th century, ceramic production in Caltagirone was known throughout Sicily and was also exported beyond the island. During this period, alongside the widespread production of wares for apothecaries, wedge-shaped bricks were also produced for the cladding of the spire of the mother church of Enna, which later collapsed in 1676 (Daidone, 2005, p. 56; Reginella, 2003, p. 20). In the second half of the century, however, conditions became less favourable, and the 1693 earthquake further aggravated the situation by destroying many workshops. The recovery following the earthquake was difficult, and production in this period shows technical shortcomings (Daidone, 2005, pp. 60-61; Ragona, 1955, p. 54; Reginella, 2003, p. 27).

In the second half of the 18th century, the workshops near the Church of San Giuliano were demolished for hygienic reasons and to allow for the construction of the

2 Plural of *cannataru*, a Sicilian term referring to potters specialised in the production of *cannate*, large terracotta vessels, often glazed, traditionally used for storing and transporting water.

3 Plural of *quartararu*, a Sicilian term referring to potters specialised in the production of *quartare*, large glazed or unglazed terracotta containers traditionally used for storing liquids and food supplies.

4 Plural of *stazzunaru*, a term from Sicilian traditional vocabulary referring to workers involved in the various operational phases of ceramic production, from material preparation to support activities for shaping and firing.

Bourbon prison. From the district of the *cannatari*, ceramic artisans moved closer to the clay quarries, in the district of San Giacomo, opposite the Church of Sant'Orsola, while some kilns were privately built near the Church of San Pietro (Ragona, 1955, p. 70; Reginella, 2003, p. 28). During this period, numerous coverings in wedge-shaped bricks for bell tower spires were produced by Caltagirone workshops. In 1751, master ceramicists Antonio Blandini, Francesco Palazzo, Nunzio Campoccia, and Nunzio Branciforti produced the bricks for the maiolica cladding of the bell tower of the Church of Madonna degli Angeli in Caltagirone, featuring a geometric decoration in white, yellow, green, blue, and manganese, designed by S. Gugliata and no longer extant. Other similar coverings produced by Caltagirone craftsmen are still present on the spires of bell towers of the following churches: Maria Ss. Annunziata in Acireale (CT), the Mother Church of Pedara (CT), San Benedetto in Cerami (EN), Santa Maria della Consolazione in Mascalucia (CT), San Pietro in Adrano (CT), the Mother Church of Palagonia (CT), San Giuseppe in Mazzarino (CL) (Reginella, 2003, p. 28), Sant'Antonio Abate in Aidone (EN), the Mother Church of Caltanissetta, San Francesco in Piazza Armerina (EN), Signore dell'Olmo in Mazzarino (CL), and the Mother Church and Santa Maria della Stella in Barrafranca (EN) (Reginella, 2015b, p. 141, note 1).

In the report prepared by Giuseppe Corona for the Italian Industrial Exhibition of 1881, it is noted that in Caltagirone there were seven factories producing household wares and seven producing bricks, which marketed their products throughout Sicily; however, production was described as not particularly significant. It is also noted that the most important factory belonged to the Di Bartolo family and that traditional kilns and the potter's wheel were used, with all production carried out manually (Reginella, 2003, p. 41; Reginella, 2015b, p. 135).

In 1918, the “Regia Scuola di Ceramica” was established by Don Luigi Sturzo, with the aim of restoring the prestige of the declining ceramic tradition of Caltagirone. In the post-war period, the ceramicist and scholar Antonino Ragona took over the direction of the school and founded the Museum of Ceramics in Caltagirone in 1965. Law no. 188 of 1990 officially recognised Caltagirone, together with Burgio, Santo Stefano di Camastra and other Italian cities, for the “protection of artistic and traditional ceramics and quality ceramics” and granted designation of origin status for its production, marked by a specific label (Reginella, 2015b, pp. 138-141).

Naso

The town of Naso, in the province of Messina, has long been inhabited by ceramic artisans, and even the etymology of its name – literally “river of mud” – suggests the presence of abundant clay deposits. During the 15th-16th centuries, trade with Spain – and in particular with Valencia – was very intense, and numerous imported ceramic products have been identified, both Spanish and Genoese, facilitated by the many fairs held on the island, which fostered the exchange of luxury goods. The master Girolamo Lazzaro, originally from Naso and later active in Palermo, owned two workshops, one

equipped with a *stazzone*⁵ in the Bazia district and another within the town. A document dated 1725 attests to the presence of a kiln also in the San Giacomo district, where other *stazzoni* likely existed. In the 17th century, brick production was both widespread and of good quality.

Naso was one of the production centres of partially glazed wedge-shaped bricks used for the construction of bell tower spires. In these workshops, wedge-shaped bricks were produced for the mother church of Santa Maria Assunta and for the Church of Sant'Alfio in Mirto (ME), as well as for the Church of Santa Barbara in Castell'Umberto (ME) (formerly Castania). In particular, the spire of the mother church of Mirto was constructed by the ceramicists Antonio Ciconaro, Marco Mormino, and Rosario Controscheri using three thousand seven hundred glazed wedge-shaped bricks.

At the end of the 18th century, the workshops of Naso entered a period of decline due to competition from products imported from Naples. During the 19th century and into the early 20th century – when production was gradually absorbed by the centre of Santo Stefano di Camastra – the output mainly consisted of building materials such as bricks, roof tiles, and *catusi*⁶ (Reginella, 2003, pp. 77-91).

Collesano

Ceramic production in the Madonie town of Collesano (province of Palermo) can be traced back to the 7th century BC and to the medieval period (11th-12th century), as evidenced by archaeological finds uncovered during excavations at Monte d'Oro. This production is closely linked to the exploitation of clay extracted from the quarries in the locality of Bovitello (Daidone, 2005, p. 170; Reginella, 2003, p. 152; Termotto, 2005, p. 439).

With regard to production in Collesano, the identification of the locations of quarries and *stazzoni* has been particularly important over time. As previously mentioned, the most extensively exploited quarries were those in the Bovitello area – a district located approximately ten kilometres from the town centre – where a distinctive *sabbia nigra* (dark sand) was extracted. The main extraction sites include: the quarry of Timpa della Cannella, the quarry of Buonfornello (white sand), the quarry known as *a li serri bianchi*, the quarry among the rocks of the Fiume di Lino (today the Roccella stream; white sand), and the quarry among the rocks of the Mora stream – which skirts the town before flowing into the Fiume di Lino (white sand) (Termotto, 2005, pp. 439-445).

As for the *stazzoni*, many were located in the district known as Stazzone – formerly named after the Convent of San Francesco – outside the town and near the Mora stream, which was essential for water supply during production processes. Most *stazzoni* were situated at a distance from the urban centre, where mainly the so-called *robba grossa* was produced, namely bricks, roof tiles, and *catusi*. In addition to meeting the needs of

5 A term from traditional Sicilian vocabulary (*stazzuni*) referring to the complex of spaces dedicated to ceramic production, including areas for clay processing, shaping, and the firing kiln. The term does not refer to a single productive element, but to the organised ensemble of the production site.

6 Terracotta pipes, often glazed only internally, designed to be connected in sequence for the construction of gargoyles and downpipes, and in some cases also used as infill elements in the construction of lightweight vaulted roofs.

the local community, these products were also supplied to other centres in the Madonie area and along the coastal zone (Termotto, 2005, pp. 439-445).

Many kilns were owned by confraternities and religious institutions. The Confraternity of San Francesco owned a kiln in the Stazzone district, one in the Ciaramitaro area, and another “*allo ponti*”. The Confraternity of San Giovanni Battista, on the other hand, owned three kilns in the districts of Cammisini and Ciaramitaro⁷. Furthermore, along Via Bagherino, on the outskirts of the town, additional kilns were owned by long-established artisan families, including the Barbera, Cellino, and Carrà (Reginella, 2003, p. 152; Termotto, 1997, pp. 35-36).

Production increased thanks to the arrival of ceramicists from other Sicilian production centres – such as Giuseppe Savia from Burgio, who established brick workshops – and through family ties, as in the case of Filippo Rizzuti from Palermo, who married into a family of Collesano ceramicists following Savia’s death, and Giovanni Saldo from Polizzi (Reginella, 2003, p. 152; Termotto, 1997, pp. 39-40).

In the 18th century, production mainly consisted of ceramic tiles for flooring and pottery, whereas in the following century floor tile production declined, and artisans focused increasingly on everyday pottery and maiolica figurines (Reginella, 2003, p. 154; Reginella, 2015a).

From the 19th century onwards, ceramic production in Collesano entered a gradual decline, likely due to competition from more technologically advanced industries. One of the last active kilns was that acquired by the ceramicist Letterio Iachetta from the Barbera family in Via Bagherino (Reginella, 2003, p. 154). In 1861, the mayor of Collesano reported the presence of nine operating kilns in the Stazzone district as part of a survey conducted by the Ministry of Agriculture, Industry, and Commerce of the Kingdom of Italy (Gambaro, 2014, pp. 47-48; Termotto, 2005, p. 467).

Today, a modern industrial facility producing bricks is located in the Bovitello area (Termotto, 2005, p. 439).

Wedge-shaped bricks were also produced in Collesano for the construction of polychrome spires. Documentary sources record that in 1579 the Confraternity of San Giacomo commissioned the maiolica artisans Simone and Antonio Gurrera of Collesano to supply four thousand polychrome bricks for the spire of the Church of San Giacomo – now no longer extant. In 1633, a payment of 1.3 *onze*⁸ was recorded to produce 334 bricks for the same spire, likely for repair works (Reginella, 2003, p. 152; Termotto, 1997, p. 36). In 1730, wedge-shaped bricks were produced – likely locally, given the presence of a kiln – by Pietro Cellino for the right-hand spire of the Church of Santa Maria di Loreto in Petralia Soprana (PA). The spire of the Church of Santa Maria la Vecchia – probably dating to the 17th century – is today composed of four thousand bricks, partly reused from the spire of San Giovanni Battista, which collapsed in 1932. The bricks of

⁷ The kilns owned by the Confraternity of San Giovanni Battista were *furnum tegularum*, that is, kilns for the production of roof tiles; however, it is likely that other objects such as *quartare*, vessels, and bricks were also produced (Termotto, 1997, pp. 35-36).

⁸ *Onza* (plural *onze*) is a historical Sicilian monetary unit in use until the 19th century, corresponding to a gold-based currency used in the Kingdom of Sicily.

the spire of the Church of Santo Stefano in Geraci Siculo (PA), for which maintenance expenses are documented as early as 1623, are also likely attributable to production in Collesano. The spire of the mother church of the same town was initially commissioned to Collesano ceramicists, who, however, did not complete the work, which was later finished by craftsmen from Santo Stefano di Camastra. The bulbous spire of the Church of San Mauro Abate in San Mauro Castelverde (PA) may also be attributed to production in Collesano (Reginella, 2003, pp. 157, 166-167). In 1782, the administrators of the Church of San Vito in Vicari (PA) commissioned the masters Pietro Pizzillo and Francesco Testaiuti to produce 3,656 bricks for the octagonal base of the bell tower and 5,263 bricks for the conical spire, with precise specifications regarding shape and dimensions (Termotto, 2005, p. 464). In 1818, wedge-shaped bricks were requested from ceramicists in Collesano for the spire of the Church of San Giovanni Battista in Ciminna (PA), but these were not delivered, and the commission was instead fulfilled by the Burgio ceramicist Pietro Valenti (Termotto, 2005, p. 474).

Burgio

Ceramic activity in the small agricultural and commercial centre of Burgio (province of Agrigento) is primarily determined by the availability of raw materials. The town is located on a slope near the Garella stream, which has historically facilitated both access to water resources and the extraction of clay; moreover, the presence of woodlands ensured a steady supply of fuel for kiln firing. The production of terracotta is documented as early as 1448, through a lease contract for premises intended for tile production by ceramicists from Sciacca. In the second half of the 16th century, the beginning of maiolica production is attested, coinciding with the arrival in Burgio of master ceramicists from Caltagirone. The emergence and growth of this production during this period can be attributed not only to the ease of raw material procurement mentioned above, but also to the presence of local craftsmen already engaged in terracotta production and to the proximity of a loading port, which allowed for the rapid import of tin, lead, and pigments, as well as the distribution of finished products towards the mainland (De Miro, 2008, pp. 11-15; Reginella, 2003, p. 171).

In 1595, the master ceramicist Vincenzo Maurici from Caltagirone moved to Burgio, where he purchased three workshops in the Giaramidaro district; he was followed by Antonio Merlo, Bartolomeo Daidone, Pietro Gangarella, Giuseppe Savia, Giacomo Sperlinga, and Stefano Vinci. For this reason, early Burgio ceramics display many characteristics comparable to those of Caltagirone (Reginella, 2003, p. 171). Archaeological excavations carried out in the early 2000s in two areas of the potter's quarter, known by the toponym *nall'arte* – one located in Via Santa Croce and the other in Vicolo Vallone – brought to light remains associated with the earliest ceramic workshops of Burgio, particularly kiln waste deposits dating back to the late 16th century. The area of Contrada Garella – named after the stream – appears to have been dedicated to the production of both domestic and building ceramics. Other *stazzoni*, dating between the 16th and 17th centuries, were located in Contrada di lu Gurgu, Contrada Sancti Rocchi and extra Portam Santi Rocchi, in Contrada de lo Mulinello, in the Portelle district, and in the Felice district (Parello, 2008, pp. 21-28; Sorgi, 2008, pp. 113-114).

In the 17th century, the influence of Caltagirone ceramics began to decline in favour of models from Palermo and Sciacca (Daidone, 2005, p. 132). Between the 17th and 18th centuries, Burgio workshops – in addition to producing pottery – supplied large quantities of floor bricks and, from the late 18th to the 19th century, were influenced by the Neapolitan market of *riggiole*, adapting to its decorative style without, however, improving production techniques (Reginella, 2003, pp. 178, 186).

Artisans in Burgio also specialised in the production of maiolica wedge-shaped bricks. Examples of spires built using these products can be found in the Church of San Giuseppe and the Church of Santa Maria della Motta in Burgio, as well as in the Church of the Concezione in Sambuca di Sicilia (AG). In 1817, Pietro Valenti produced nine thousand bricks for the Church of the SS. Crocifisso in Burgio and two thousand for the Church of Sant'Antonio Abate in Ciminna (PA) (Reginella, 2003, pp. 186, 189). Moreover, during the 19th century, the production of green and yellow glazed roof tiles, known as *canaluna*, was widespread; these were placed on roofs in correspondence with balconies and windows to provide protection from rain and sunlight (Sorgi, 2008, p. 115).

At the end of the 19th century, ceramic production in Burgio began to decline, due both to competition from Neapolitan production and to a cholera epidemic. From the second half of the 19th century until the mid-20th century, approximately twenty workshops were still active; however, the rise of industrial manufacturing gradually relegated Burgio production to decorative ceramics and tourist-oriented artefacts (Sorgi, 2008, p. 115).

Santo Stefano di Camastra

Ceramic production in Santo Stefano di Camastra (province of Messina) began later than in other centres in Sicily. The town, rebuilt after the landslide that destroyed the original settlement in 1682, was relocated to an area rich in clay deposits. The first *stazzoni* were established in the early 18th century near the clay quarries of Torremuzza by ceramicists Rosario Pecura and Rosario Silvestri from Pettineo, Stefano and Michele Di Noto from Caronia, and Rosario Pizzuto, a local *stazzonaro*. Subsequently, Michele Armao founded the first workshop specialised in glazing techniques. In the second half of the 18th century, additional master ceramicists from Caltagirone, Barcellona Pozzo di Gotto, and Patti moved to Santo Stefano. In the 19th century, artisanal production gradually evolved into industrial production, thanks to Gaetano Armao, who experimented with new manufacturing techniques in the *stazzone* of Chjanu; in the second half of the century, the factory's output reached approximately fifteen thousand maiolica bricks (Reginella, 2003, pp. 193, 195, 197).

The production of maiolica wedge-shaped bricks for the construction of bell tower spires was particularly significant. Examples include the two small domed coverings of the bell towers of the Church of the Calvario and the dome of the bell tower of the town's mother church. The mother church of Geraci Siculo (PA) was completed using bricks supplied from Santo Stefano, as the ceramicists of Collesano were unable to complete the production.

In the report for the Italian Industrial Exhibition held in Milan in 1881, twelve fac-

tories in Santo Stefano di Camastra are recorded, with a total annual production of approximately 510,000 ceramic tiles. However, in the 20th century, production began to decline, and in the post-war period bricks were no longer produced, with output limited to everyday objects (Reginella, 2003, pp. 201, 204).

Gangi

Ceramic production in the Madonie centre of Gangivecchio (province of Palermo) is documented from the 14th century onwards. In 1363, a Benedictine monastery was founded, within which the monks were also engaged in ceramic production. The location of Gangivecchio played a key role in the establishment of the monastery – both for the availability of water resources, clay, and woodland, and for its position at the intersection of important routes that facilitated exchanges with much of Sicily.

The *stazzone* and the kiln to produce roof tiles and bricks remained active until the 17th century under the control of the Benedictines and – during the most profitable periods – under the management of *gabelloti*⁹ and tenants, even after part of the monastic community relocated to Castelbuono. The last tenants, the Bongiorno family – who later became the owners – maintained ceramic production by carrying out maintenance works on the kiln. In 1772, they undertook interventions on the *stazzone*, warehouses, and associated dwellings, and constructed three new kilns and spaces for clay processing. During this period, tin-glazed bricks were produced for the mother church of Gangi, along with wedge-shaped bricks for bell tower spires. This production includes the dome of the mother church dedicated to San Nicolò and the spires of the bell towers of the Churches of SS. Salvatore and San Cataldo in Gangi; a further hypothesis – still to be verified – concerns the spire of the Church of Santa Caterina in Mistretta (ME) (Agrò, 2018a, pp. 101-102; Agrò, 2018b, pp. 11-12, 23-26; Gambaro, 2014, pp. 22-23).

6.1.2 - Localisation and Distribution of Ceramic Wedge-Shaped Brick Spires

The territorial distribution of ceramic wedge-shaped brick spires directly reflects the production dynamics outlined in the previous paragraph, highlighting a close relationship between the places where these elements were manufactured and their areas of diffusion across the Sicilian territory.

The analysis is based on a corpus of catalogued spires, for which data have been collected regarding the associated building, formal typology, chronology, and – where documented – the provenance of the ceramic elements. These data are systematised in Table 5 to allow for a synoptic and comparative reading, while the spatial distribution of the cases is represented through cartographic mapping, supporting the identification of territorial concentrations and patterns of diffusion (Figure 11).

From a geographical perspective, ceramic wedge-shaped brick spires are predomi-

⁹ *Gabelloto* (plural *gabelloti*), a historical figure in the Sicilian context, referring to an agrarian intermediary who leased (in *gabella*) land and natural resources on behalf of landowners, exercising economic control over their exploitation.

Table 5. Wedge-shaped brick spires identified to date in Sicily. Names and locations were identified through bibliographic references, online sources, and local documentation. Spire geometry was identified through visual assessment, based on in situ observation or on satellite and street-level imagery. Construction dates and production centres are based on the following sources: ^aReginella, 2003; ^bDi Paola et al., 2018; ^cLi Rosi & Russo, 2024; ^dSapienza, 2010; ^eReginella, 2013; ^fReginella, 2015; ^gAgrò, 2018a; ^hFiorilla, 2013.

PROVINCE	MUNICIPALITY	MAIN NAME	SPIRE GEOMETRY	CONSTRUCTION DATE	PROVENANCE OF CERAMIC MATERIAL
AG	Burgio	S. Giuseppe	pyramidal	1623 ^a	Burgio ^a
AG	Burgio	Beata Maria Vergine Immacolata	double curvature		Burgio ^a
AG	Casteltermini	S. Giuseppe	double curvature		
AG	Cattolica Eraclea	Purgatorio	double curvature		
AG	Cattolica Eraclea	S. Antonio di Padova	double curvature	18th c. ^b	
AG	Lucca Sicula	Maria Ss. Del Rosario	double curvature		
AG	Sciacca	S. Agostino	hemispherical		
AG	Villafranca Sicula	S. Giovanni Battista	pyramidal		
CL	Butera	San Rocco	hemispherical		
CL	Delia	S. Maria di Loreto	hipped		
CL	Mazzerino	S. Giuseppe	bulbous	18th c. ^b	Caltagirone ^a
CL	Mazzerino	Ss. Crocifisso dell'Olmo	bulbous		
CL	Santa Caterina Villermosa	Maria Ss. delle Grazie	pyramidal		
CT	Acireale	Maria Ss. Annunziata	conical	1729-1732 ^c	Caltagirone ^a
CT	Acireale	Maria Ss. Annunziata	conical	1887-1890 ^c	Caltagirone ^a
CT	Adrano	S. Pietro	conical		Caltagirone ^a
CT	Caltagirone	S. Maria di Gesù	pyramidal	18th c. ^b	
CT	Caltagirone	Maria Ss. del Ponte			
CT	Mascalucia	S. Maria della Consolazione	pyramidal	18th c. ^b	
CT	Palagonia	S. Pietro	pyramidal		
CT	Pedara	S. Caterina Alessandrina vergine e martire	conical		Caltagirone ^a
CT	Tremestieri	S. Maria delle Grazie	conical	18th c. ^b	
CT	Vizzini	S. Vito	double curvature		
EN	Agira	S. Filippo	pyramidal		
EN	Agira	S. Antonio da Padova	pyramidal		
EN	Agira	S. Antonio Abate	conical		
EN	Aidone	S. Giuseppe	conical		
EN	Aidone	S. Antonio Abate	conical	18th c. ^b	
EN	Barrafranca	Maria Ss. della Stella	double curvature		

EN	Barrafranca	Maria Ss. della Purificazione	hemispherical		
EN	Cerami	S. Sebastiano	conical		
EN	Cerami	S. Ambrogio	hemispherical	18th c. ^b	
EN	Enna	Maria Ss. Addolorata	hemispherical	1744 ^b	
EN	Gagliano Castelferrato	S. Cataldo	conical		
EN	Leonforte	S. Stefano	conical		
EN	Leonforte	S. Antonio di Padova	conical		
EN	Piazza Armerina	Anime Sante del Purgatorio	pyramidal		
EN	Piazza Armerina	S. Francesco	conical		
EN	Regalbuto	del Collegio di Maria	hipped	1740 ^b	
EN	Troina	Maria Ss. del Carmelo	conical		
EN	Valguarnera Caropepe	S. Anna	conical		
EN	Valguarnera Caropepe	S. Antonio	conical		
ME	Castell'Umberto	S. Barbara	conical	18th c. ^b	Naso ^a
ME	Mirto	S. Alfio, Cirino e Filadelfio	hemispherical		Naso ^a
ME	Mirto	S. Maria di Gesù	conical		
ME	Naso	Nostra Signora della Consolazione	conical		
ME	San Pietro Patti	Madonna delle Grazie	conical		
ME	San Teodoro	chiesa di Borgo Giuliano	conical	1940 ^d	S. Stefano di Camastra ^d
ME	Santo Stefano di Camastra	del Calvario	hemispherical		S. Stefano di Camastra ^a
ME	Santo Stefano di Camastra	S. Nicola	hemispherical		
ME	Tortorici	S. Francesco	conical		
ME	Tusa	S. Giovanni Battista	conical		
ME	Tusa	S. Nicola	conical		
ME	Ucria	Maria Ss. del Rosario	conical		
PA	Bisacquino	S. Maria delle Grazie	hemispherical	18th c. ^b	
PA	Bisacquino	S. Francesco d'Assisi	double curvature	18th c. ^b	
PA	Bisacquino	S. Maria del Balzo	double curvature		
PA	Bisacquino	S. Francesco di Paola	pyramidal		
PA	Cefalà Diana	S. Francesco di Paola	mixed profile		
PA	Chiusa Sclafani	S. Sebastiano	double curvature		
PA	Ciminna	del Purgatorio	pyramidal		
PA	Ciminna	S. Giovanni Battista	hipped	1817	Burgio
PA	Ciminna	S. Antonio Abate	pyramidal	18th c. ^b	

PA	Collesano	S. Maria la Vecchia	conical	17th c. ^e	Collesano ^f
PA	Contessa Entellina	S. Maria del Bosco	pyramidal	1750 ^b	Burgio ^f
PA	Corleone	S. Maria di Gesù	double curvature		
PA	Corleone	S. Francesco di Paola	mixed profile		
PA	Gangi	S. Cataldo	conical	1776 ^b	Gangi ^{is}
PA	Gangi	Ss. Salvatore	conical	18th c. ^f	Gangi ^{is}
PA	Geraci Siculo	S. Maria Maggiore	conical	1844 ^e	Collesano/S. Stefano di Camastra ^e
PA	Geraci Siculo	S. Stefano	conical	ante 1623 ^a	Collesano ^f
PA	Giuliana	Maria Ss. del Rosario	hemispherical	18th c. ^b	
PA	Isnello	S. Maria Maggiore	conical		
PA	Mezzojuso	Crocifisso	pyramidal		
PA	Monreale	Madonna del Rosario di Tagliavia	mixed profile		
PA	Monreale	Madonna del Rosario di Tagliavia	mixed profile		
PA	Montemaggiore Belsito	Maria Ss. delle Grazie	conical		
PA	Montemaggiore Belsito	del Ss. Crocifisso	double curvature	18th c. ^b	
PA	Petralia Soprana	S. Maria di Loreto	conical	1730 ^e	Collesano ^e
PA	San Mauro Castelverde	S. Mauro Abate	mixed profile	17th c. ^f	Collesano ^f
PA	Vicari	S. Marco	conical		
RG	Acate	Madonna del Carmelo	double curvature	1794 ^b	
RG	Comiso	S. Biagio	double curvature		
RG	Ragusa Ibla	S. Vincenzo Ferreri	double curvature	17th c. ^h	Caltagirone ^h
RG	Vittoria	S. Giuseppe	hipped		

nantly concentrated in the inland areas of Sicily, with particularly significant diffusion in the Madonie region, in the inland areas of the province of Palermo, and in the central and eastern parts of the island. Their presence is more sporadic along the coastal belt, except for some cases located near major urban centres or historical production hubs. This distribution suggests a strong connection with inland settlement contexts, where ceramic spires play a prominent role as architectural landmarks within the built landscape.

The localisation of the identified cases shows a clear relationship with the presence of the main ceramic production centres documented for the manufacture of wedge-shaped bricks – namely Caltagirone, Burgio, Collesano, Naso, Santo Stefano di Camastra, and Gangi. In many cases, the provenance of the materials is confirmed by documentary sources, supporting supply dynamics that favour geographical proximity, particularly in relation to artefacts characterised by a high degree of technical and decorative special-

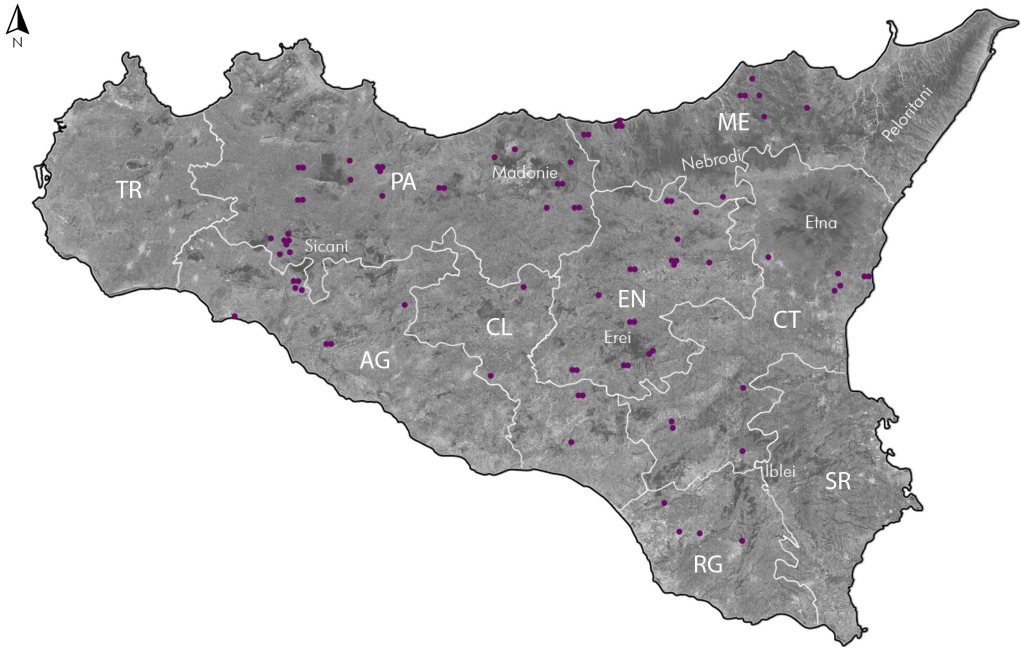


Figure 11. Mapping of the glazed wedge-shaped brick spires identified to date within the Sicilian territory.

isation. Where such information is not available, the territorial clustering and typological and formal affinities nonetheless allow for the hypothesis of coherent production and distribution networks consistent with those known for the regional ceramic centres.

In terms of contexts of use, ceramic wedge-shaped brick spires are found in ecclesiastical buildings of varying typology and scale, located both in medium-sized urban centres and in small inland villages. Their presence therefore does not appear to be strictly linked to the status or importance of the building, but rather to the intention to characterise its crowning element through a recognisable formal and material solution, capable of conferring visibility and identity to the architectural organism within its settlement context.

From a chronological perspective, the collected data indicate a higher concentration of spires between the 17th and 18th centuries, with the phenomenon persisting throughout the 19th century and with some isolated cases in the contemporary period. This timeframe corresponds to a phase of particular vitality in Sicilian ceramic production specialised in building components, as well as to a period of intense construction activity and renewal of ecclesiastical buildings, often following seismic events or reconstruction and expansion works.

The analysis of formal typologies highlights a clear predominance of conical spires across the entire territory, followed by double-curvature, hemispherical, and pyramidal forms – both square and octagonal. Typologies characterised by greater geometric and constructive complexity – such as mixtilinear, or bulbous – are less frequent within the analysed corpus, suggesting that their limited diffusion is related to greater executorial complexity.

The integrated interpretation of territorial distribution, chronological data, and production information provides the basis for a perceptual analysis of ceramic wedge-shaped brick spires, understood as visual and symbolic landmarks within the urban and landscape context, and allows the phenomenon to be framed within a broader territorial dimension.

6.1.3 - The Ceramic Spire as a Landmark: Architectural Prominence and Spatial Perception

The diffusion of ceramic wedge-shaped brick spires across the Sicilian territory is best understood through an integrated approach that combines quantitative and distributive data with an analysis of their perception within the urban and landscape context. By virtue of their elevated position and their role as crowning elements of buildings, spires acquire a strong visual significance, configuring themselves as prominent and immediately recognisable elements within the built environment, capable of significantly shaping the overall image of the settlement.

From a perceptual perspective, the combination of form, position, and material endows spires with a particular ability to attract attention. Their placement at the top of bell towers enhances their visibility in relation to the surrounding urban fabric, while their geometry – often simple and clearly legible in conical or pyramidal forms – reinforces their perception as the concluding element of the architectural organism. These characteristics make the spire a key visual reference, recognisable and memorable, in line with the dynamics identified by Kevin Lynch in the construction of the image of the city (Lynch, 1964).

Within the urban context, ceramic spires actively contribute to the definition of the



Figure 12. Perceptual sequence of spires within consolidated urban contexts. From left: Basilica of Santa Caterina in Pedara (CT), Church of San Pietro in Adrano (CT), Basilica Cattedrale of Maria SS. Annunziata in Acireale (CT).

skyline, particularly in historic centres characterised by compact and relatively low-rise building fabrics. Their presence introduces a clear visual hierarchy, in which the bell tower and its spire stand out as emergent elements within the built profile. The perception of these elements is often constructed through a sequence of partial and progressive views along streets, squares, and open spaces, following patterns that recall the concept of “serial vision” described by Gordon Cullen (Cullen, 1961), in which the architectural element gradually emerges and acquires meaning through its dynamic relationship with movement and urban space (Figure 12).

This capacity for visual prominence extends also to the territorial scale, particularly in the inland areas of Sicily, where many settlements are located on hills, ridges, or slopes. In these situations, the bell tower spire transcends the purely urban dimension and becomes a recognisable feature within the surrounding landscape, visible even from medium and long distances. When approaching a settlement along the main access routes, the ceramic spire acts as an anticipatory element of the built environment, contributing to its identification and strengthening the perceptual relationship between architecture and territory (Figure 13).

A central role in this process is played by the ceramic material and, in particular, by the presence of glazing. Glazed surfaces, consistently characterised using colour, introduce a chromatic discontinuity with respect to the underlying masonry and re-



Figure 13. Perception of ceramic spires in the landscape. Top left: Church of Maria SS. di Loreto in Petralia Soprana (PA); top right: Church of San Cataldo in Gagliano Castelferrato (EN); bottom left: Church of Maria SS. Assunta in Castelbuono (PA); bottom right: Church of Sant'Antonio Abate in Ciminna (PA).



Figure 14. Examples of spires clad in glazed wedge-shaped bricks: the interaction between the modularity of the bricks and incident light defines the chromatic and formal rendering of the coverings, enhancing their perception at a large scale. Left: spire of the Church of Santa Maria delle Grazie in Tremestieri Etneo (CT); right: northern spire of the Basilica Cattedrale of Maria SS. Annunziata in Acireale (CT).

spire sensitively to solar radiation, generating reflections and perceptual variations that change throughout the day and according to atmospheric conditions. This behaviour gives the spires a dynamic visual quality, enhancing their perceptual impact and continuously renewing their interpretation. From a material and constructive perspective, the use of wedge-shaped bricks allows for the precise definition of curved or inclined surfaces, making the overall form of the spire legible even at a distance. The modularity of the elements and the regularity of their arrangement contribute to an ordered and coherent perception of the envelope, in which colour, light, and geometry are closely interconnected with construction techniques. In this sense, the perceptual effect is not the result of an autonomous decorative intervention, but rather emerges from the integration of formal solution, material, and construction system (Figure 14).

Considered as a whole, ceramic wedge-shaped brick spires can be understood as elements of strong visual impact, capable of operating simultaneously across multiple scales of interpretation – architectural, urban, and landscape – and of contributing significantly to the construction of the image of settlements. Their recurrence across the Sicilian territory suggests the existence of a shared perceptual language, in which the ceramic spire becomes a distinctive and identity-defining feature of the built landscape, consolidating the relationship between ceramic production, construction techniques, and the representation of space.



Figure 15. Glazed wedge-shaped bricks. Top: solid bricks from the spires of the Basilica Cattedrale Maria SS. Annunziata in Acireale (CT); bottom: hollow bricks from the spire of the Church of San Pietro in Adrano (CT).

6.1.4 - From Material to Form: Laying Systems and Decorative Schemes

The spires of Sicilian bell towers are frequently constructed using modular ceramic elements known as wedge-shaped bricks, sometimes also referred to as *zoccoli* or *bugnette*¹⁰. The use of these elements allows for the effective covering of curved or inclined surfaces, combining structural requirements, protection against atmospheric agents, and formal quality. Their diffusion attests to the existence of a well-established technical knowledge, capable of adapting to different geometric and constructive solutions (Figure 15).

From a material perspective, wedge-shaped bricks are glazed ceramic elements, comparable to traditional bricks in terms of composition and production process, but characterised by a form specifically designed for use in coverings with complex geometry. At one end, they present an exposed head – which may be curved, polygonal, or sometimes diamond-shaped – while along the longitudinal axis they taper, assuming a wedge or truncated pyramidal configuration. The exposed head is the only portion of the element subjected to atmospheric elements and is therefore glazed to ensure impermeabil-

¹⁰ The information presented in this paragraph is partly based on existing literature on ceramic roofing in Sicily (Di Paola et al., 2018; Di Paola et al., 2020; Fatta & Vinci, 2024; Fiorilla, 1986; Fiorilla, 2013; Li Rosi & Russo, 2022; Reginella, 2013).

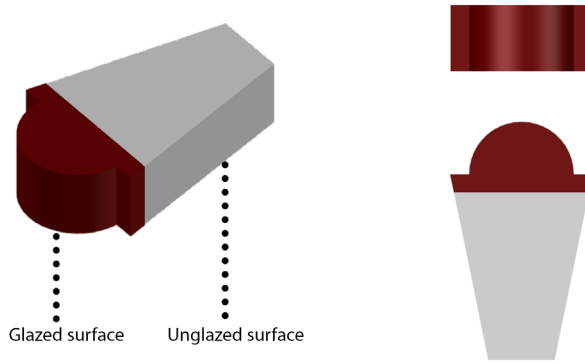


Figure 16. Wedge-shaped solid brick with a glazed curved head.

ity and durability, while also enabling the use of colour as a defining aesthetic feature. The non-visible portion, by contrast, retains the roughness typical of raw brick, which enhances adhesion with the bedding mortar.

Wedge-shaped bricks could be produced either solid or hollow, depending on constructive requirements and local production practices. Hollow elements were laid either with the cavity facing downward – left empty to reduce weight – or upward, filled with mortar during installation; solid and hollow bricks could feature grooves or incisions on the bedding surfaces, improving the bond with the mortar. These elements were sometimes complemented by pieces adapted during the forming stage – such as those obtained by halving the brick while the clay was still fresh – allowing for the resolution of specific geometric conditions without interrupting the continuity of the system (Figure 16).

Regarding the construction system, wedge-shaped bricks could be used either as the primary load-bearing structure of the covering or as a cladding applied to an underlying structure made of masonry, wood, or metal. When functioning as the main structural element, their installation follows methods comparable to those of double-leaf brick masonry, with horizontal courses and staggered vertical joints (Figure 17). The elements are arranged concentrically, following the geometry of the spire, and bonded with mortar.

In relation to the geometry of the covering – particularly in conical and spherical cases – construction initially requires maintaining a constant number of bricks in each course. As the courses follow circumferences of progressively decreasing diameter, a gradual reduction in the width of the vertical joints occurs towards the top. When these

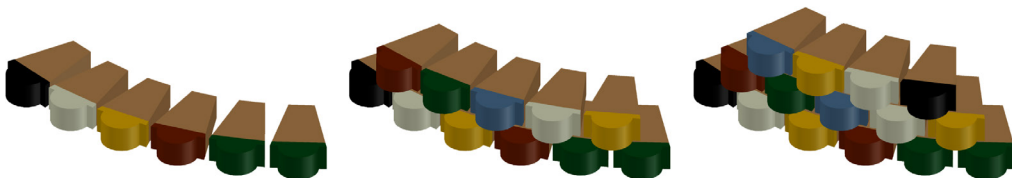


Figure 17. Construction scheme of a conical wedge-shaped brick spire (concentric courses with horizontal bedding and staggered vertical joints).

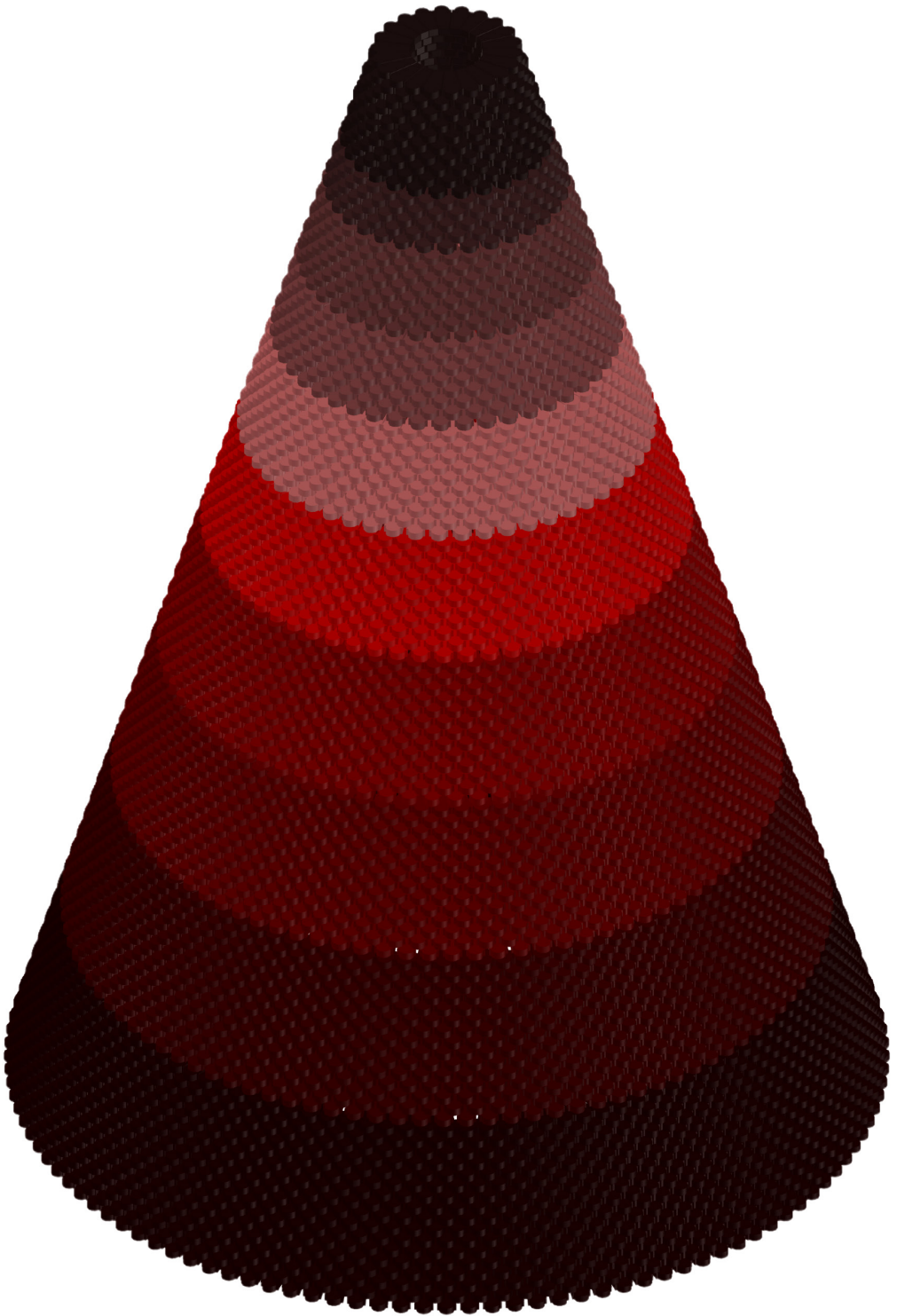


Figure 18. Model of a conical spire. The differently coloured bands identify courses composed of an equal number of bricks.



Figure 19. Examples of crowning elements of wedge-shaped brick spires. From left: southern spire of the Basilica Cattedrale Maria SS. Annunziata in Acireale (CT); spire of the mother church Santa Maria della Consolazione in Mascali (CT); spire of the Basilica of Santa Caterina in Pedara (CT); spire of the Church of Santa Maria delle Grazie in Tremestieri Etneo (CT).

joints become excessively narrow, making installation difficult, the number of elements in the subsequent course is reduced, restoring joints of adequate thickness. To accommodate this complex geometry, wedge-shaped bricks were produced with different tapering angles and varying lengths, adapting to the progressively reduced sections of the spire.

Spires are generally organised into horizontal bands, each composed of courses made with bricks of the same size (Figure 18). The use of progressively shorter elements with greater tapering allows for a natural reduction in the thickness of the structure towards the apex.



Figure 20. Examples of internal stiffening systems in spires. From left: southern and northern spires of the Basilica Cattedrale Maria SS. Annunziata in Acireale (CT); spire of the Church of Santa Maria delle Grazie in Tremestieri Etneo (CT).



Figure 21. Examples of internal stiffening systems in spires. From left: southern and northern spires of the Basilica Cattedrale Maria SS. Annunziata in Acireale (CT); spire of the Church of Santa Maria delle Grazie in Tremestieri Etneo (CT).

The uppermost part is usually completed by a stone element acting as a keystone, placing the upper courses in compression and contributing to the overall stability; metal elements such as crosses, weathervanes, or wind vanes are often mounted on top of it (Figure 19).

Within the structure, stiffening and bracing systems could be present, such as timber frames arranged in a cross pattern or metal ‘cage’ reinforcements, sometimes equipped with external anchor heads carefully concealed (Figure 20).

From a decorative perspective, individual wedge-shaped bricks are generally monochromatic and, when considered in isolation, lack intrinsic ornamental value. The decorative pattern of the spires is therefore not inherent to the single element but emerges during installation through the arrangement of pieces according to predefined geometric schemes. The design arises from the modular organisation of the elements, following a compositional principle like that of mosaic art, in which the final outcome depends directly on the arrangement of modules rather than on painted decoration applied in the workshop.

The most common decorative motifs found in ceramic wedge-shaped brick spires consist of horizontal bands of uniform or alternating colour, oblique bands, zigzag patterns, and diamond-shaped compositions, all achieved exclusively through the modular arrangement of monochromatic elements (Figure 21). Despite their apparent simplicity, these schemes allow for a wide variety of formal solutions and adapt effectively to curved surfaces, ensuring a clear reading of the design even from a distance.

The need to reduce the number of bricks in certain courses inevitably affects the continuity of decorative patterns. At these transitions, builders introduced deliberate variations in the ornamental scheme, modifying the direction of the pattern or interrupting it, for example, through monochromatic horizontal bands (Figure 22). These solutions – widely observed in existing examples – demonstrate how decorative choices were closely subordinated to the constructive and geometric requirements of the covering.

In some cases, the spire is set on a drum, which mediates the transition between



Figure 22. Discontinuities in decorative patterns (highlighted in red) due to the reduction in the number of bricks from one course to the next.

the shaft of the bell tower and the covering itself (Figure 23). Wedge-shaped bricks are also used not only in main spires but in the construction of secondary pinnacles, in the cladding of ribs, corners, window surrounds, and cornices, contributing to a coherent diffusion of ceramic language across the entire architectural organism (Figure 24).

Overall, materials, construction technique, and decorative appearance contribute to defining a unified system, in which the formal outcome of ceramic wedge-shaped brick spires is the direct result of the integration between geometry, production process, and

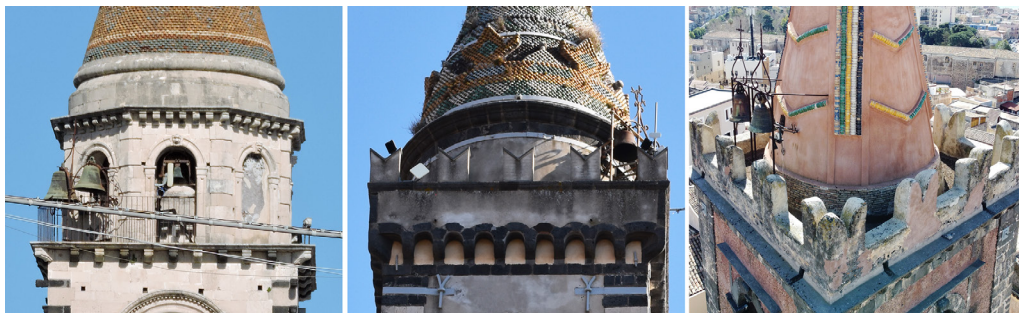


Figure 23. Examples of drums supporting spires. From left: southern spire of the Basilica Cattedrale Maria SS. Annunziata in Acireale (CT); spire of the Basilica of Santa Caterina in Pedara (CT); spire of the Church of San Pietro in Adrano (CT).

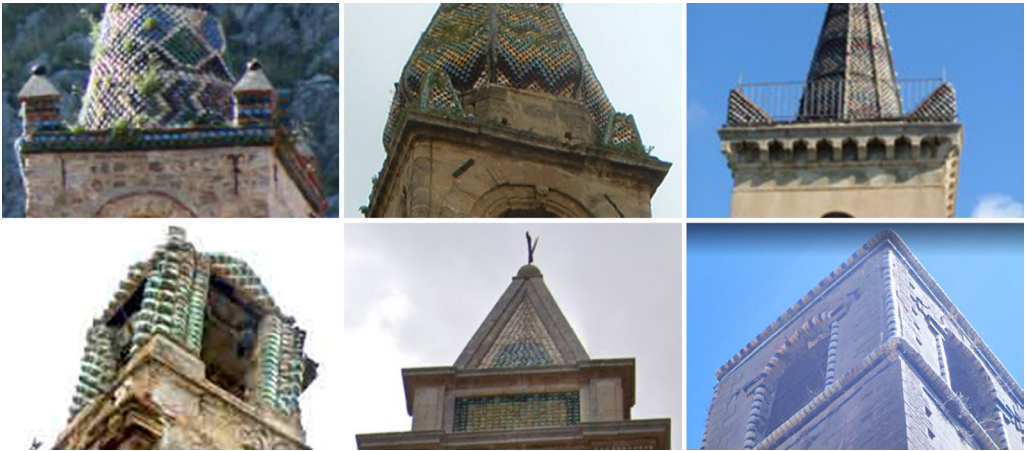


Figure 24. Examples of other applications of glazed wedge-shaped bricks. Top row, from left: Church of Santa Maria Maggiore, Isnello (PA); Church of Signore dell'Olmo, Mazzarino (CL); Church of Santa Maria la Vecchia, Collesano (PA). Bottom row, from left: Church of San Francesco di Paola, Corleone (PA); Church of San Francesco di Paola, Bisacchino (PA); Church of San Giuseppe, Aidone (EN).

laying techniques. The complexity of the adopted solutions and the level of control required during construction highlight how these coverings represent the expression of a technical knowledge capable of combining structural requirements, material durability, and formal quality.

6.1.5 - Analysis of Conservation State and Alteration Phenomena

Ceramic elements used in spires – whether as cladding or, in the case of wedge-shaped bricks, also as structural components – are particularly exposed to atmospheric elements due to their elevated position. In most cases, they cannot benefit from the protection provided by surrounding buildings against water, wind, and solar radiation.

The metal element typically placed at the top of the spire represents a point of vulnerability for several reasons. Ceramic components may exhibit stains caused by iron oxide resulting from the oxidation of exposed metal elements; moreover, when metal elements are embedded within the ceramic pieces, oxidation processes and thermal expansion and contraction due to temperature variations can lead to the cracking or failure of the elements themselves. The placement of heavy elements – in stone or metal – at the apex of maiolica spires places additional stress on their structural stability, particularly during seismic events and in the absence of fastening systems capable of preventing the sinking of these elements into the spire and the consequent damage to any internal bracing systems. The slender, vertically developed structure of spires – especially when topped with a cross or a weathervane – is particularly susceptible to lightning strikes and to wind action, which generates lever effects. The need to access the extrados of spires for inspection and maintenance has often led to the creation of openings using questionable methods, which have weakened the structural equilibrium and introduced additional metal elements into the system. The arrangement of wedge-shaped bricks forming a spire favours the accumulation of soil deposits and, consequently, the proliferation of

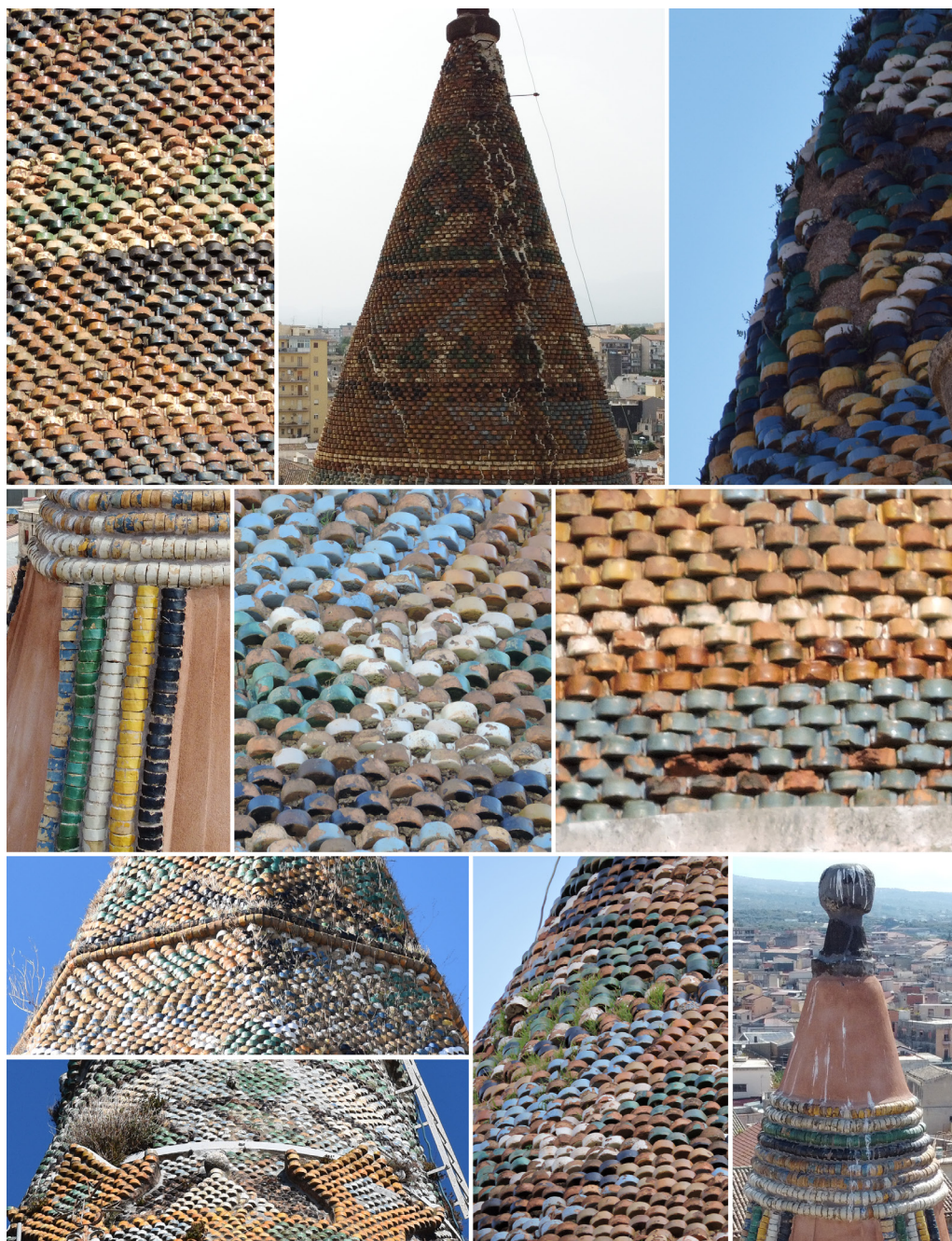


Figure 25. Main forms of deterioration in ceramic spires. Top row: left, fracture in the brick facing where the mortar has completely disintegrated and the bricks are no longer in contact; centre, fracture (at the location of iron elements inserted as a maintenance ladder) repaired with mortar infill, altering the external appearance of the architectural element; right, mortar infill in correspondence with missing bricks. Middle row: left and centre, glaze surface eroded due to water and wind; right, ceramic body eroded due to water and wind. Bottom row: left and centre, presence of invasive vegetation within the cavities between bricks, which favour the accumulation of soil transported by wind; right, presence of guano.

invasive vegetation. Root systems exert both chemical and mechanical actions, degrading mortar joints and bricks, widening cracks, and facilitating further water infiltration, additional soil accumulation, and the continued growth of vegetation. These deposits are particularly significant in those elements that present an upward-facing concavity (Figure 25) (Fatta & Vinci, 2024; Li Rosi & Russo, 2022; Li Rosi & Russo, 2024).

6.2 - Ceramic Roofing in the Valencian Community

In the Valencian region, glazed ceramics find one of their most characteristic architectural expressions in the cladding of domes, which appear both within urban areas and in religious buildings located in the rural landscape. In both cases, the ceramic dome emerges as a highly recognisable element that stands out visually in the built environment and plays a significant role in shaping the character of the place. The combined use of glazed ceramics and the colour blue represents one of the most distinctive features of Valencian architecture and has become a defining element of its visual identity. The blue chromatic scheme, often combined with white, symbolically recalls the colour of the celestial vault, reinforcing the symbolic and spiritual value of the dome in religious architecture.

From a historical perspective, the dome was introduced into Spanish architecture during the Renaissance, particularly through the adoption of models *a la romana* constructed in brick masonry. The need to protect these structures from humidity and rainwater infiltration encouraged the development of glazed ceramic roofing systems capable of providing greater waterproofing than traditional solutions. The earliest documented example of a brick masonry dome covered with glazed tiles dates back to 1595 in the Iglesia del Colegio del Corpus Christi, also known as Colegio del Patriarca. This building, together with the Monasterio de San Miguel de los Reyes, represents one of the earliest examples of the introduction of Renaissance architectural language in Valencia and marks the starting point for the diffusion of this type of roofing. From these early models, numerous churches were subsequently built first within the city of Valencia and later throughout the surrounding territory, contributing to the development of a construction tradition that would later converge in the so-called Valencian Baroque.

Between the seventeenth and eighteenth centuries, the use of glazed ceramics as an architectural covering for domes became particularly widespread, in conjunction with a period of intense building activity and with the cultural and religious climate promoted by the Counter-Reformation. During this period, the ceramic-clad dome acquired a significance that went beyond its purely protective function. It became a strongly characterised architectural element from both a symbolic and representational perspective, expressing the renewed role of the Church within urban space. The use of majolica surfaces, clearly visible in the skyline of a largely flat city characterised by buildings of relatively uniform height, helped to strengthen the visual recognisability of religious buildings and to shape the overall image of the city. In this context, the glazed *teja árabe* progressively established itself as the preferred solution for covering domes and, more generally, as a defining element of Valencian religious architecture, extending its use also to smaller roofing structures. The continuity of this practice gradually consolidated

a construction and figurative tradition that remained active until the end of the nineteenth century and the beginning of the twentieth, when glazed ceramics were once again reinterpreted within Modernist architecture in dialogue with other ceramic and decorative coverings (Gil Saura et al., 2006, pp. 13-61, 63-77).

Within this framework, the study of Valencian ceramic domes makes it possible to investigate the relationship between ceramic production and architectural application, between construction techniques and visual expression, as well as the role of ceramics in shaping the urban and territorial landscape. The following sections therefore examine ceramic production in the Valencian region, the distribution of domes, perceptual and landscape aspects, the materials and construction systems employed, and finally the main forms of deterioration affecting these roofing systems.

6.2.1 - History and Techniques of Ceramic Production in the Valencian Region

Ceramics constitute a significant component of the material culture of the Valencian region and represent a long-standing and articulated productive tradition that includes utilitarian wares, artistic productions, and architectural applications. This development is closely linked to the favourable conditions offered by the territory: the availability of suitable clays, the abundance of water ensured by the hydraulic system connected to the Turia River and the network of *acequias*¹¹, as well as access to woodland resources necessary for firing the kilns, all constitute determining factors for the establishment and continuity of ceramic production. These conditions help explain why ceramic production developed in a particularly intense and structured way in the Valencian region, encouraging the concentration of workshops and their long-term continuity (Coll Conesa, 2009; Pérez Guillén, 1996).

From a chronological perspective, Valencian ceramic production is attested from the earliest phases of human settlement and underwent complex developments between the pre-Roman, Roman, Late Antique, and medieval periods (Coll Conesa, 2009, pp. 7-38). A particularly significant phase corresponds to the Islamic period (8th–13th centuries), during which a substantial advancement in production techniques took place: the use of the fast wheel spread widely, glazing practices became consolidated, and decorative techniques such as *cuerda seca* , green and manganese decoration, and metallic lustre were introduced. During this period, workshops also became more organised and craftsmen increasingly specialised, factors that contributed to the development of the technical heritage of Valencian ceramic production (Coll Conesa, 2009, pp. 39-54).

Within this general framework, several production centres played a major role in the history of Valencian ceramics. Paterna emerged as one of the earliest centres, with documented production already between the 13th and 14th centuries, mainly related

¹¹ *Acequias* are artificial irrigation channels derived from river watercourses, dating back to the Islamic period, used for the distribution of water for agricultural, productive, and urban purposes. In the Valencian territory they form a historical hydraulic network connected to the Turia River, which played a fundamental role in water supply and in the development of craft activities.

to utilitarian and decorative ceramics (Coll Conesa, 2009, pp. 55-112; Real Academia de Cultura Valenciana, 1997, pp. 14-15). Manises, on the other hand, became a major production centre between the 14th and 15th centuries, gaining wide recognition for its glazed and decorated ceramics, which characterise its period of greatest development in the medieval and late medieval periods (Coll Conesa, 2009, pp. 55-112; Real Academia de Cultura Valenciana, 1997, pp. 16-18, 22-24). In the 18th century, the Alcora manufactory was added to these centres; founded as the Real Fábrica, it was oriented towards high-quality production and characterised by organisational and stylistic models distinct from those of traditional centres and from productions intended for urban architectural applications (Coll Conesa, 2009, pp. 177-194; Real Academia de Cultura Valenciana, 1997, pp. 19-21).

During the 16th century, the persistence of already well-established technical skills was gradually accompanied by influences related to Italian Renaissance culture, particularly regarding the expansion of the colour palette and the use of polychromy. Commercial and artistic contacts with Italian centres contributed to the introduction of new decorative schemes and to a greater compositional complexity, which found application especially in ceramics intended for architectural use, laying the foundations for the formal developments of the early modern period (Pérez Guillén, 1996, p. 9).

Alongside utilitarian and decorative ceramics, a specific production linked to architecture also developed, including cladding elements, flooring, and ceramic components intended for buildings. This production was characterised by different aims and modes of manufacture and was conceived in close relation to the architectural structures for which it was intended, thus forming an autonomous productive field within the broader Valencian ceramic panorama (Pérez Guillén, 1996, pp. 15-55). In the early modern period, the production of these elements was closely connected to the urban context of the city of Valencia, where workshops and kilns dedicated to architectural ceramics were located in direct relation to the main construction sites, often supplying materials specifically produced for the buildings under construction (Pérez Guillén, 1996, pp. 9-13).

During the seventeenth and eighteenth centuries, in conjunction with a period of intense building activity, architectural ceramic production reached its peak. During this period, glazed ceramics were systematically employed in both religious and civil constructions, assuming a central role in shaping the architectural image of the city of Valencia and of the surrounding centres.

Against this background, which highlights the plurality of Valencian ceramic manufactures and the specific role of architectural production in the early modern period, the discussion can now focus on ceramic roofing systems and, in particular, on domes covered with glazed ceramics, analysing their distribution, construction characteristics, and their significance within the urban and territorial context.

6.2.2 - Localisation and Distribution of Domes

The distribution of domes covered with glazed ceramics in the Valencian territory is analysed by distinguishing between urban and extra-urban areas. For the city of Valencia, it is possible to reconstruct a more systematic framework based on the identification



Figure 26. Ceramic domes in Valencia. Above: domes of the Iglesia del Colegio del Corpus Christi and the Iglesia de la Santísima Cruz; below: domes of the Basílica de Nuestra Señora de los Desamparados, the Ayuntamiento, and the Mercado Central.

of buildings featuring ceramic domes, their location, and their main formal and decorative characteristics. For smaller settlements and for the rural context, the analysis relies instead on a selection of representative cases, which nevertheless allow the patterns of diffusion of this architectural model beyond the main urban context to be outlined.

Within the urban fabric of the city of Valencia, domes and roofs covered with glazed ceramics are significantly concentrated and are mainly associated with religious buildings. The group of identified cases makes it possible to recognise a coherent urban nucleus in which the use of ceramic roofing constitutes a recurring and recognisable solution, although expressed through a variety of forms and decorative schemes (Figure 26). Among the earliest examples is the dome of the Iglesia del Colegio del Corpus Christi, also known as Colegio del Patriarca, which represents one of the first documented applications of this type of cladding in the Valencian urban context (Gil Saura et al., 2006, pp. 73-76).

From a morphological point of view, urban ceramic roofs display a variety of solutions, including domes set on circular and octagonal plans, as well as smaller domes crowning lanterns and bell towers. Domes with an elliptical plan, on the other hand, rep-

resent isolated cases, limited to only two examples within the analysed sample (Iglesia de la Santísima Cruz and Basílica de Nuestra Señora de los Desamparados), confirming the marginal character of this solution compared with the more widespread geometries.

Regarding materials, glazed ceramic roofing tiles represent the most common solution for covering domes. The use of ceramic shingles is documented in a smaller number of cases and is mainly associated with more recent interventions (Gil Saura et al., 2006, pp. 143-145), suggesting a later chronology compared with roofs constructed using traditional tiles. A certain variety can also be observed in chromatic and decorative terms, despite the presence of recurring patterns: combinations based on shades of blue with ribs highlighted in white, horizontal bands, or simple geometric motifs are predominant, while only a few solutions employ green, yellow, and brown.

Alongside religious buildings, several significant examples of ceramic roofing can also be found in public buildings, demonstrating that the use of glazed ceramic cladding extends beyond the strictly religious sphere. In particular, cases such as the City Hall (*Ayuntamiento*) and the Central Market (*Mercado Central*) show how ceramic roofing was also adopted in representative civic contexts, contributing to the definition of the overall urban image (Figure 26).

Table 6. Ceramic roofs in the city of Valencia. Building names and construction periods are based on bibliographic references and online sources; the remaining information – roof type, plan form, ceramic material, roof colours, and decoration type – was derived from in situ visual assessment.

BUILDING	CONSTRUCTION PERIOD	ROOF TYPE	PLAN FORM	CERAMIC MATERIAL	ROOF COLOURS	DECORATION TYPE
Iglesia de San Miguel y San Sebastián (1)	1726-1739	dome	octagonal	roof tile	blue and brown	brown ribs
		lantern dome	octagonal	roof tile	blue and brown	brown ribs
Iglesia de la Santísima Cruz (5)	16th-17th c.	dome	elliptical	roof tile	blue and white	double white ribs
		lantern dome	octagonal	roof tile	blue and white	white ribs
		bell tower dome	octagonal	roof tile	blue and white	white ribs
Edificio Marqués de Campo (3)		dome	octagonal	shingle	green and yellow	horizontal bands
		pitched roof		Marseilles tile	green and yellow	diamond pattern
		tower spire	square	shingle	green and yellow	zigzag pattern
Monasterio del Corpus Christi (2)		dome	octagonal	roof tile	blue and white	white ribs
Iglesia de Nuestra Señora del Puig (4)	1875	dome	octagonal	shingle	blue and white	white ribs
		tower spire	square	shingle	blue and white	zig-zag

Iglesia de las Escuelas Pias (6)	1767-1771	dome	circular	roof tile	blue and white	double white ribs
		lantern dome	circular	roof tile	blue and white	white ribs
		bell tower dome	square	roof tile	blue and white	double white ribs
Mercado Central (9)	1914-1928	dome	circular	shingle	grey	none
		dome	circular	ceramic mosaic	turquoise and yellow	geometric-floral pattern
		small domes	circular	shingle	yellow	none
Iglesia de los Santos Juanes (7)	14th c.	dome	circular	roof tile	blue and white	white ribs
		lantern dome	circular	roof tile	blue and white	white ribs
		lateral apse semi-dome	square	roof tile	blue and white	double white ribs
Iglesia del Sagrado Corazon de Jesus (8)		dome	octagonal	roof tile	blue and white	white ribs
		bell tower spire	square	roof tile	blue and white	double white ribs and geometric patterns
Basílica de Nuestra Señora de los Desamparados (14)	1652-1666	dome	elliptical	roof tile	blue	none
		lantern dome	elliptical	roof tile	blue	none
Catedral de la Asunción de Nuestra Señora (13)		lateral domes	octagonal	roof tile	blue and white	white ribs
Ayuntamiento de Valencia (10)		small lateral domes	circular	shingle	copper (metallic lustre)	none
Iglesia de San Martin (11)		dome	octagonal	roof tile	blue and brown	brown ribs
		small dome	circular	roof tile	blue and brown	brown ribs
		lateral apse semi-dome	square	roof tile	blue and brown	brown ribs
Iglesia de San Juan de la Cruz (12)	1602-1615	dome	octagonal	roof tile	blue and white	white ribs
		bell tower dome	octagonal	roof tile	blue and white	white ribs
Iglesia del Patriarca o del Corpus Christi (18)	1586-1615	dome	circular	roof tile	blue and white	horizontal bands
		lantern dome	circular	roof tile	blue and white	horizontal bands

Iglesia de Santo Tomás y San Felipe Neri (17)	1727-1736	dome	octagonal	roof tile	blue and yellow	yellow ribs
		lantern dome	octagonal	roof tile	blue and yellow	yellow ribs
		bell tower dome	square	roof tile	blue and yellow	yellow ribs
Convento de Santo Domingo (19)	13th c.	dome	circular	roof tile	brown (metallic lustre)	none
		lantern dome	circular	roof tile	brown (metallic lustre)	none
		bell tower dome	circular	roof tile	brown (metallic lustre)	none
		dome	circular	roof tile	yellow	none
		lantern dome	circular	roof tile	yellow	none
Iglesia del Temple (16)	1770	bell towers domes	square	roof tile	blue	none
		dome	circular	roof tile	blue	none
		lantern dome	circular	roof tile	blue	none
Universidad Católica de Valencia San Vicente Mártir (15)		dome	circular	roof tile	blue and white	white ribs
		lantern dome	circular	roof tile	blue and white	white ribs
Colegio de San Pio V (Museo de Bellas Artes) (20)	18th c.	dome	octagonal	roof tile	blue	none
		lantern dome	octagonal	roof tile	blue	none
Monasterio de San Cristobal (21)	19th c.	dome	octagonal	shingle	blue and white	white ribs and geometric patterns
Iglesia del Sant Angel Custodi (22)		dome	circular	roof tile	green and white	white ribs
		lantern dome	circular	roof tile	green and white	white ribs
		bell tower dome	circular	roof tile	green and white	white ribs
Santuario de Nuestra Señora de Monteolivete (23)		dome	octagonal	roof tile	blue and white	white ribs
Monasterio de San Miguel de los Reyes (24)	17th c.	dome	circular	roof tile	blue	none

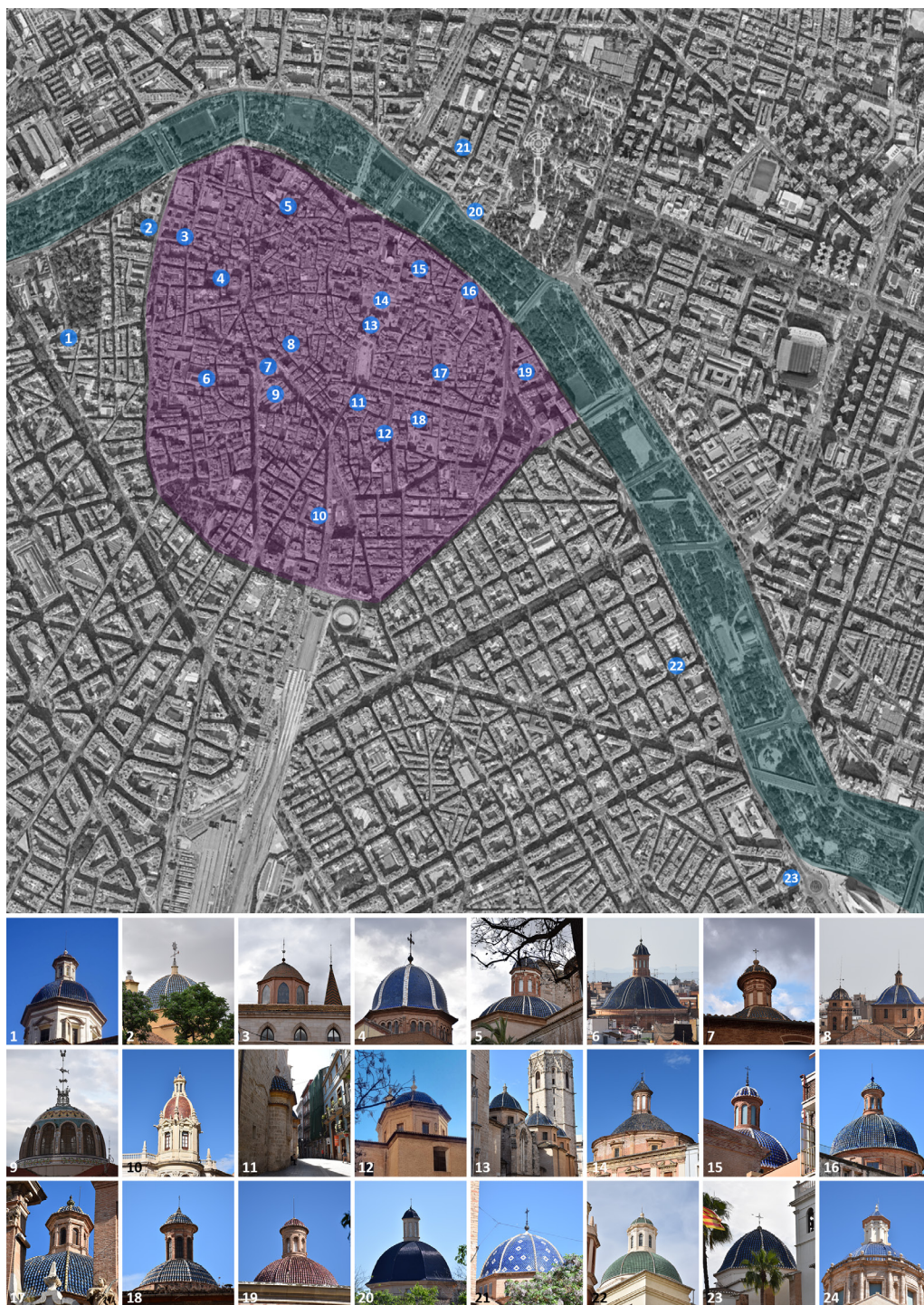


Figure 27. Identification of ceramic domes in the city of Valencia (the numbers correspond to Table 6). In purple: the ancient city; in green: Turia Park.



Figure 28. Ceramic domes outside the city of Valencia. From left: Real Monasterio de Santa María de la Valldigna, Simat de Valldigna, Valencia; Monasterio de San Miguel de los Reyes, Rascanya, Valencia; Ermita de Sant Josep, Xàtiva, Valencia.

The data relating to the domes and ceramic roofs identified within the urban fabric of Valencia are presented in tabular form (Table 6), in order to enable a comparative analysis of their main formal, material, and decorative characteristics. They are accompanied by a cartographic representation highlighting their spatial distribution within the city (Figure 27). These tools provide the basis for the subsequent considerations on the diffusion of the model and on the perceptual role of ceramic domes within the urban context.

Outside the urban context of the city of Valencia, the presence of domes and roofs covered with glazed ceramics appears less systematic and more difficult to reconstruct exhaustively. In these cases, ceramic roofs are mainly associated with religious buildings and are found both within smaller settlements and in churches isolated within the rural landscape (Figure 28). These cases show a substantial continuity with the solutions adopted in the urban context, both in terms of materials and in their formal and decorative characteristics, suggesting a circulation of models and craftsmen from the urban centre towards the surrounding territory.

The presence of ceramic domes outside the urban context therefore does not appear to result from independent processes of experimentation, but rather from a process of diffusion of the architectural language developed in the city. In this sense, rural cases and those located in smaller settlements can be interpreted as expressions of the capacity of the Valencian model to adapt to different settlement contexts, while maintaining a strong material and chromatic recognisability.

Overall, these examples help to outline a pattern of territorial diffusion which, although not quantitatively comparable with that observed in the urban context, remains significant for understanding the geographical and cultural extent of the use of glazed ceramic roofing in the Valencian territory.



Figure 29. Views of the city of Valencia from the Torres de Serranos and Torres de Quart, Valencia.

6.2.3 - The Ceramic Dome as a Landmark: Architectural Prominence and Spatial Perception

The diffusion of domes covered with glazed ceramics in the Valencian context cannot be interpreted solely through distributional or typological data, but also requires reflection on the ways in which these structures are perceived within urban and territorial space. In the case of the city of Valencia, this perception is strongly conditioned by the repeated presence of domes within a dense and relatively homogeneous urban fabric, which makes them recurring and familiar elements of the city's image.

From a perceptual point of view, the elevated position of domes on religious and civic buildings gives them a privileged position in relation to the surrounding built environment (Figure 29). However, within the compact urban context of the city of Valencia, the visual value of domes is expressed not so much through the dominance of indi-



Figure 30. Views of the city of Valencia featuring domes covered with glazed tiles. Above: Iglesia de Santo Tomás y San Felipe Neri, Mercado Central, Edificio Marqués de Campo, Iglesia de las Escuelas Pías. Middle: Basílica de Nuestra Señora de los Desamparados, Monasterio de San Cristóbal, Colegio de San Pío V (Museo de Bellas Artes), Iglesia de Santo Tomás y San Felipe Neri. Below: Iglesia del Temple, Iglesia de Santo Tomás y San Felipe Neri, Iglesia de los Santos Juanes.

vidual isolated landmarks, but rather through a widespread and continuous presence. Observations conducted through photographs taken from elevated viewpoints clearly reveal this condition: the observer can simultaneously perceive several domes distributed throughout the urban fabric, emerging among the roofs and forming a constant and recognisable visual pattern.

At the urban scale, the perception of ceramic domes is often shaped through a se-



Figure 31. Ceramic roofs observed from open spaces such as squares, wider urban spaces, or major streets. Above: Colegio de San Pío V (Museo de Bellas Artes), Basílica de Nuestra Señora de los Desamparados. Middle: Catedral de la Asunción de Nuestra Señora, Iglesia del Temple. Below: Ayuntamiento de Valencia, Convento de Santo Domingo, Santuario de Nuestra Señora de Monteolivete.

quence of partial glimpses and intermittent appearances. In many cases, the surrounding built environment limits the complete view of the architectural organism, allowing only portions of the domes, lanterns, or ceramic-covered spires to emerge. This fragmented mode of perception, documented through photographs taken at street level, recalls dynamics similar to the “serial vision” described by Gordon Cullen, in which the experience of urban space unfolds as a succession of views that progressively reveal architectural elements in relation to movement and the built environment (Cullen, 1961) (Figure 30). In other cases, however, the opening of squares, wider spaces, or visual axes allows a more complete reading of the dome, which appears in its entirety, emphasising its monumental character (Figure 31).



Figure 32. Behaviour of coloured glazed ceramic roofs under natural light. Above: Colegio de San Pío V (Museo de Bellas Artes), Catedral de la Asunción de Nuestra Señora, Ayuntamiento de Valencia. Middle: Iglesia del Temple, Convento de Santo Domingo, Monasterio de San Miguel de los Reyes. Below: Colegio de San Pío V (Museo de Bellas Artes), Iglesia de las Escuelas Pías, Iglesia de los Santos Juanes.

The repetition of the type contributes to strengthening the recognisability of ceramic domes as visual reference elements within the urban image. In this sense, they can be interpreted as recurring components of the mental image of the city, comparable to rec-



Figure 33. Left: dome of the Ermita de la Sang among traditional roofs in the town of Sagunt, Valencia. Right: Cartuja de Ara Christi in the countryside of the town of El Puig de Santa María, Valencia.

ognisable and memorable landmarks according to dynamics similar to those identified by Kevin Lynch in the construction of the urban image (Lynch, 1964). Their perceptual effectiveness lies not so much in the exceptionality of the individual structure, but in the frequency with which these elements accompany the everyday experience of urban space.

A decisive role in this perception is played by the glazed ceramic material and by the use of colour. The glazed surfaces introduce a clear chromatic discontinuity in relation to traditional roofs and the underlying masonry and respond strongly to natural light, generating reflections and perceptual variations that change throughout the day and according to atmospheric conditions (Figure 32). This dynamic visual quality amplifies the perceptual impact of the domes and constantly renews their visual reading.

In smaller settlements and in the rural landscape, the perception of ceramic domes assumes a different configuration. In these contexts, characterised by lower building density and greater visual openness, the dome assumes a more isolated and punctual role, emerging as a recognisable sign in relation to the surrounding built environment or the agricultural landscape (Figure 33). Its visibility is often emphasised by the elevated position of the religious building and by the possibility of being perceived from a greater distance, which confers on the dome the value of a territorial reference rather than that of an element repeated within the urban fabric.

6.2.4 - From Material to Construction: Roofing Systems and Decorative Schemes

The ceramic material used in the roofing of Valencian domes is designed to meet specific functional requirements related to the protection of masonry structures from moisture and to the durability of the roof covering. The tiles must ensure waterproofing in order to prevent water infiltration, be sufficiently light so as not to place excessive loads on the supporting structure, have a shape that facilitates the rapid runoff of rain-water, and possess adequate hardness and mechanical resistance, allowing them to be walked on during maintenance operations. These tiles have a truncated conical shape

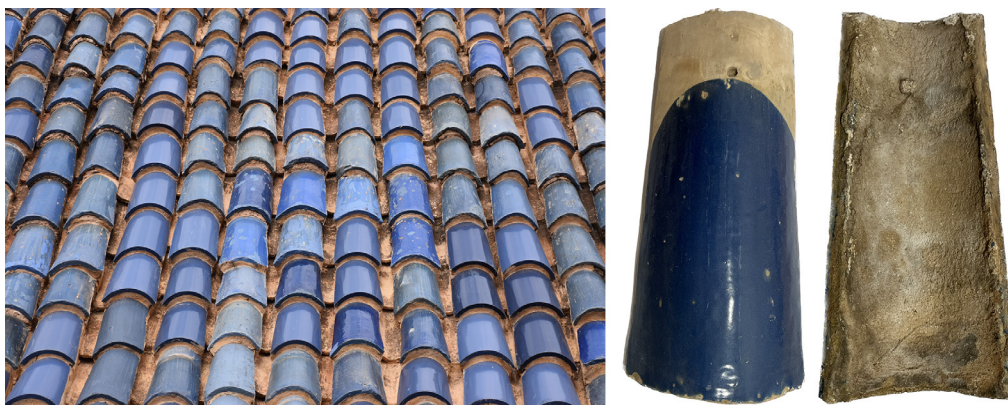


Figure 34. Blue tiles of the dome of the Escuelas Pías, Valencia.

with a curved profile that allows them to interlock and form a continuous and resistant roof covering.

From the fourteenth century onwards, these requirements found an effective response in the progressive diffusion of the curved tile, commonly referred to as *teja árabe*. Before the widespread adoption of this element, roofs were constructed using two distinct types of tiles: channel tiles (*canales*), used for the collection and flow of rainwater, and cover tiles (*cobijas*), which protected the joints between the channels. With the introduction of the curved tile, the same element began to be used in both positions; however, the terms *canal* and *cobija* continued to be used to indicate the different placement of the tile within the roof covering.

Glazing is applied exclusively to the elements intended to remain visible, corresponding to the cover tiles, while the channel tiles, placed in the lower part of the roof covering, generally remain without a vitreous coating. Glazing is applied in particular to the convex external surface of the cover tile, which is most exposed to atmospheric agents and visually perceptible, while the inner surface retains the roughness of the fired clay, favouring adhesion during installation (Figure 34).

Over time, in order to accommodate the geometric complexity of roofs – especially curved and articulated surfaces such as those of domes – a range of ceramic elements with specific formal characteristics was developed. These include ridge tiles (*caballetes* or *cumbreras*), which are larger and shaped to ensure adequate coverage along ridge lines and hips, as well as hip tiles (*limatesas*), used at the junctions between roof slopes. These elements are complemented by additional special pieces, such as half tiles or lateral elements that facilitate installation and maintenance operations, as well as components with a mainly decorative function, including spheres or tiles with relief elements.

From the mid-nineteenth century onwards, alongside the continued use of curved tiles, flat tiles of different types were introduced, in particular fish-scale tiles (*en escama* or *cola de castor*). These elements are characterised by a semicircular lower edge that overlaps the upper portion of the tile below, producing a continuous texture resembling the surface of fish scales (Figure 35).

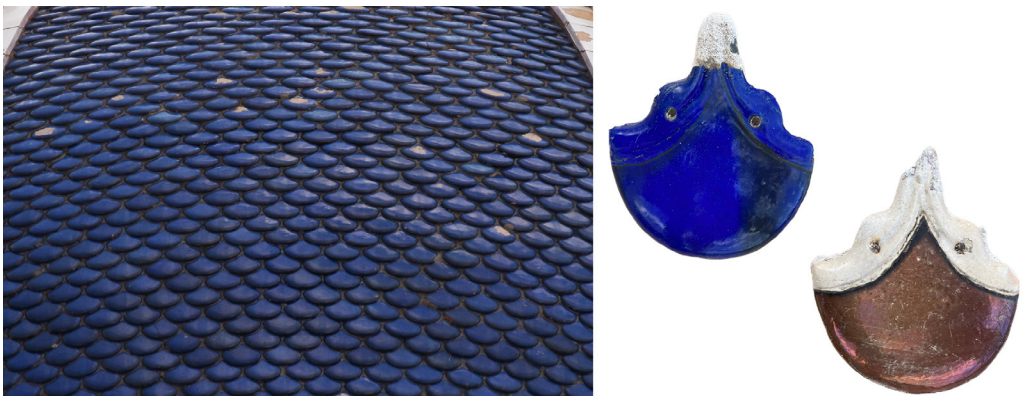


Figure 35. Fish-scale tiles. Left: roof covering of the Iglesia de Nuestra Señora del Puig, Valencia; right: fish-scale tiles from the original roof covering of the Iglesia de Nuestra Señora de Sales, Sueca, Valencia.

From a production perspective, manual manufacture using moulds represented the most widespread technique for producing tiles until the beginning of the twentieth century, allowing a flexible production process adaptable to the different formal and functional requirements of roofs, including curved surfaces such as domes. In most cases, the tiles were produced in the workshop already provided with a hole in the upper part, which allowed them to be directly fixed to the support by nailing or by suspension with wire.

The construction system of Valencian ceramic domes is based on the distinction between the load-bearing structure of the dome and the tiled roof covering, which performs primarily protective and finishing functions. The stability of the tiles, arranged on inclined surfaces and therefore subject to the action of gravity, is ensured through both chemical and mechanical anchoring systems, which guarantee the continuity and durability of the roof covering over time.

Chemical anchoring is achieved through the use of bedding mortars, generally lighter than those used in the construction of the dome's masonry structure. These mortars are applied in layers of variable thickness, which may range from a few centimetres to greater depths depending on irregularities in the substrate and the slopes that need to be accommodated. The composition of the mortar does not follow a single standard recipe and may include different binders, with or without lime-based binders, depending on the specific requirements of the construction site. However, the need to absorb the inevitable movements of the roof covering makes it essential to control the mechanical characteristics of the mortar, since expansion phenomena may cause the lifting of tiles and the loss of continuity of the roof covering.

Mechanical fixing is used as a complementary system, particularly in the case of flat tiles. Historically, this was achieved using wooden or metal nails inserted through small holes in the tile and subsequently concealed by the overlap of the adjacent element. This system improves the stability of individual pieces, particularly in areas most exposed to wind action or in portions of the roof characterised by steeper slopes. In general, while curved tiles are fixed mainly through the stability of the overall system, flat tiles are more frequently secured through individual mechanical fixing (Cortés Meseguer, in press; Gil Saura et al., 2006, pp. 138–146).

The most common laying system for roofs made with curved tiles is the cover-and-pan tile system (*canal y cobija*). Using a single ceramic element, the tiles are first placed with the concave side facing upward, forming channels that collect and convey rainwater; subsequently, tiles with the convex side facing upward are placed over two adjacent channels, covering the joints between them. This system, adaptable to both flat and curved surfaces, is particularly effective in ensuring the continuity of the roof covering and the proper drainage of rainwater.

In the case of domes, tiles are generally laid in horizontal courses parallel to the base, subdividing the curved surface into portions comparable to planar surfaces. The intersection of these portions generates hip lines or ribs, along which specific covering elements, such as ridge tiles, are placed. The installation sequence usually begins with the definition of the ridge and hip lines, followed by the laying of the tiles starting from the central areas of the surfaces and progressing towards the junction lines, which are finally

covered with ridge elements (Gil Saura et al., 2006, pp. 138–146).

The load-bearing structures of domes may present different constructive solutions and may be built in stone masonry or, more commonly, in brick masonry. The dome may be constructed as a solid masonry structure using concentric rings (*bóveda a rosca*), or as a thin brick vault (*bóveda tabicada*), and may consist of a single layer, a composite section, or a double shell depending on its dimensions and structural requirements. The supporting layers for the tiles may be installed dry or with the use of mortar; however, in domes, due to the variable and often steep slopes, installation with mortar is the most common and effective solution.

The slope of the tiles varies significantly along the vertical profile of the dome: it may be almost horizontal near the apex, increase progressively along the body of the shell, and decrease again near the eaves. This variability requires careful control of both the laying process and the fixing system, in order to ensure that the roof covering maintains continuity and stability in all its parts (García Bastida, 2019).

The decorative patterns of roofs covered with glazed tiles in Valencian domes are closely related both to the type of ceramic element used and to the adopted colour range. Decoration does not function as an independent ornamental layer applied to the surface; rather, it derives from the combination of tile shape, modular arrangement and colour, producing solutions that vary according to the geometry of the dome and the extent of the surface to be covered.

Colour plays a central role, particularly blue, which represents the predominant chromatic tone of Valencian domes. Traditionally associated with the sky, air and water, blue contributes to a perception of lightness in the roof covering. In Goethe's theory of colours, this hue influences the perception of depth and distance, reinforcing the visual impression of lightness in the architectural composition. This colour is almost systematically combined with white, which is used to emphasise ribs and surface articulations, creating a clear chromatic contrast that remains easily recognisable even from a distance.

From a typological perspective, in the case of the *teja árabe*, the curvature of the tiles generates a pronounced play of light and shadow that accentuates the three-dimensional character of the surface and makes the decorative effect strongly dependent on solar exposure. In the case of ceramic shingles, by contrast, the regular overlapping of the elements produces a more continuous and delicate surface in which decoration relies mainly on colour and modular rhythm rather than on plastic variation.

In traditional solutions, particularly in larger domes, the decoration is generally restrained and based on simple repetitive schemes. The main surfaces of the dome are often covered with blue glazed tiles, while the ribs are emphasised using white tiles. In some cases, the ribs are doubled or tripled, visually reinforcing the edges and the main geometric lines of the dome. Other chromatic variants combine blue with ribs formed by metallic-lustre tiles or yellow tiles. In a limited number of examples – usually associated with minor buildings, secondary domes or contexts characterised by economic constraints – blue glazed tiles are reserved exclusively for the ribs, while the rest of the surface is covered with unglazed tiles.

From the late nineteenth century onwards, decorative schemes became progressively more articulated and varied. Decoration acquired more expressive qualities while re-



Figure 36. Different decorative patterns in Valencian domes. Above: Iglesia de las Escuelas Pías, Iglesia de San Agustín (Xàtiva), Iglesia del Patriarca. Below: Edificio Marqués de Campo, Iglesia de la Asunción de Nuestra Señora (Utiel), Monasterio de San Cristóbal.

maintaining anchored to geometric principles based on modularity and repetition. In this context, ceramic shingles offer greater compositional possibilities than *teja árabe*, allowing a wider variety of patterns and chromatic arrangements. Alongside these more common solutions, sporadic cases also appear in which different colours – such as green, yellow or brown (with or without metallic lustres) – are used either on their own or confined to specific portions of the roof. These examples remain relatively rare and do not alter the overall chromatic framework dominated by the blue-white combination.

Among the recurring decorative schemes are those based on the repetition of the same colour along a preferred direction, such as horizontal bands in which colours alternate along the circular development of the dome. Such solutions may be adopted both with *teja árabe* and with shingles. Other patterns include diagonal bands or zig-zag schemes, which introduce greater visual dynamism and emphasise the ornamental character of the roof covering (Figure 36).

6.2.5 - Analysis of the State of Conservation and Alteration Phenomena

Domes covered with glazed ceramic tiles, although designed to ensure waterproofing and protect the underlying structures, are subject to different forms of deterioration related both to the overall behaviour of the roofing system and to the characteristics of the individual ceramic elements. It is therefore useful to distinguish between pathologies affecting the roof covering, attributable to construction defects or mechanical problems involving the roofing system as a whole, and pathologies affecting the tiles, which are related to their behaviour over time once they are in service.

Among the pathologies affecting the roof covering are cracks in the dome and dam-



Figure 37. Common deterioration phenomena affecting glazed tile roof coverings. Specifically: (a) horizontal crack in the roof covering, (b) vertical crack in the roof covering, (c) insufficient overlap between tiles, (d) presence of invasive vegetation, (e) fracture of the ceramic element caused by the insertion of an inappropriate element, (f) tile breakage, (g) missing tiles, (h) abrasion of the glaze, (i) cracking of the glaze.

age caused by errors in the setting-out or execution of the roof covering, which may compromise the correct arrangement of the ceramic elements. Phenomena such as the loss or absence of tiles are frequent, as well as their displacement or rotation, particularly in cases of insufficient overlap or incorrect positioning of the channel tiles. These problems are often associated with inappropriate maintenance interventions, such as the replacement of missing tiles using cement-based mortars, which alter the elastic behaviour of the roof covering and favour the development of further structural problems. Other recurring phenomena include the loss of joint mortar, the presence of invasive vegetation and the action of animals, all of which progressively contribute to the weakening of the roofing system.

With regard to the pathologies affecting the tiles, the analysis focuses on the effects of deterioration that occur during the service life of the element; defects related to the modelling and firing stages of ceramic production, such as deformations or original imperfections, are not considered here, as they are already addressed in the chapter dedicated to the deterioration of architectural ceramics in general. Once in service, glazed tiles are particularly sensitive to mechanical stresses and may show fragmentation or chipping because of impacts or localised loads. Alterations of the glazed surface are also observed, including loss or detachment of the vitreous coating, chromatic variations and the formation of superficial cavities, often related to the combined action of moisture, atmospheric agents and the composition of the pigments. In some cases, exposure to high temperatures following fires may cause bubbles, craters or significant changes in the appearance of the glaze, compromising both the functional performance and the aesthetic quality of the roof covering.

These phenomena show how the deterioration of ceramic domes results from the interaction between environmental conditions, material characteristics and the quality of construction and maintenance, making it necessary to adopt an integrated understanding of the roofing system and its components (Figure 37).



Chapter 7 - Territorial Information Model for the Documentation of Towers with Ceramic Roof Coverings

This chapter presents the implementation of the information model and the operational documentation protocol adopted for the study of towers with ceramic spires, outlining the technical and organisational choices that enabled the structuring, integration, and querying of the collected data.

The development of the information system involved translating the relationships between artefact, material, production, and territory into an integrated relational structure implemented within a PostgreSQL/PostGIS environment. This structure enables the coordinated management of alphanumeric and spatial data, allowing for a multi-level interrogation of the analysed heritage and the construction of a territorial system capable of relating towers to ceramic production centres, raw material supply areas, and their respective settlement contexts. Furthermore, the integration of the database with the GIS environment allows the representation and analysis of spatial relationships between these different elements, providing the informational basis for the territorial analyses developed throughout the research.

The chapter is organised into two sections: the first is dedicated to the translation of the conceptual model into a relational data structure, and the second to the integration of the database within a GIS environment and the construction of the territorial system.

7.1 - Translation of the Conceptual Model into a Relational Structure

The data structure was developed and managed within a PostgreSQL environment – an open-source relational database management system – with the PostGIS spatial extension, through the definition of a schema structured according to principles of data consistency and normalisation. The database design involved organising the entities identified during the conceptual phase into separate tables, each provided with specific attributes describing their identifying, morphological, and contextual characteristics.

◀ Ceramic wedge-bricks of the spire of the Church of San Pietro in Adrano (CT).

The tables are connected through relational constraints defined by primary keys and foreign keys, in order to maintain referential integrity across the different informational levels. This structure makes it possible to distinguish architectural, material, and territorial components, preserving their descriptive autonomy while ensuring the possibility of reconstructing their interrelations through cross-querying.

The adoption of the PostGIS extension also enabled the integration of the spatial dimension with the alphanumeric one, allowing for the management of georeferenced spatial data.

Database Architecture

The database architecture is structured into main tables, relationship tables, lookup tables, and tables with a geometry field. This organisation allows the separate structuring of descriptive information, relationships between entities, and the spatial component. The main tables correspond to the system entities and contain identifying and descriptive attributes related to towers, spires, production centres, quarries, and municipalities. Each entity is represented by an independent table with a unique primary key. Relationship tables manage multiple associations between entities – such as the relationship between spires and production centres or between production centres and quarries – enabling the recording of many-to-many connections without data duplication. Lookup tables standardise recurring values, ensuring terminological consistency and control over attribute domains. The spatial component is implemented through geometry fields associated with territorial entities and through geometric tables derived from vector layers originating in the GIS application. These tables are linked to the corresponding descriptive entities through shared keys, allowing the management of geometric and alphanumeric data to remain distinct while ensuring their integration within the system.

System Entities

The system entities are implemented as independent tables, each with a unique primary key and specific attributes defined according to the role of the entity within the information model. From a logical perspective, they are organised into three groups: architectural entities (tower and spire), production entities (production centre and quarry), and territorial entities (municipality). The geometric component is managed in two ways: either through separate geometric tables derived from GIS layers or directly within the descriptive table.

The tower entity represents the vertically developed architectural structure that constitutes the subject of documentation, identified as an emergent element within the built context and characterised by the presence of a roof covering that is the object of specific analysis. It includes general identifying and descriptive attributes related to the catalogued structures, such as name, identification codes, administrative classification, and chronological and typological information. The geometric component is not stored directly in this table but is instead managed through a separate table derived from the vector layer created in the GIS environment (`towers_points`), containing only the geometry field and the corresponding identifier. The integration between the descriptive and spatial components is reconstructed through a dedicated view, used for returning the

complete dataset within the GIS environment.

The spire entity represents the ceramic roof covering located at the top of the tower and constitutes the specific focus of the research. It is provided with an identifier independent of the tower. This approach allows for a detailed description of the morphological, material, and chromatic characteristics of the ceramic covering – such as shape, type of ceramic element, presence of glaze, decorative motifs, and colour scheme – separating them from the general attributes of the architectural structure. The table does not include a geometry field, as the spatial location of the spire is determined through its relationship with the tower, with which it shares territorial and geometric anchoring.

The production centre entity represents the craft or manufacturing hub where the ceramic elements used in roof coverings were produced. It includes attributes related to the identification of the production centre, its location, and available historical documentation. In this case as well, geometry is managed in a separate table derived from the vector layer created in the GIS environment (`production_centers_points`), linked to the descriptive table through a shared key. The data is reorganised via a dedicated view for operational use within a GIS environment.

The quarry entity represents the site for raw material extraction, particularly clay used for ceramic production. It includes descriptive attributes related to identification, material type, and available historical information. Similarly to towers and production centres, the geometric component is managed through a separate table derived from a GIS vector layer (`quarries_points`), linked to the descriptive table through a key and subsequently integrated via a view for use within the GIS environment.

The municipality entity represents the administrative and territorial framework within which the other entities are located. It enables the geographic and administrative contextualisation of the system. Unlike the other entities, the geometric component is stored directly within the table.

The entities, together with their primary keys, attributes, and the specification of geometric data management, are presented in the Table 7.

Relationships Between Entities

The relationships between entities define the informational connections that allow the reconstruction, starting from the architectural artefact, of its links with production contexts and its territorial framework. In particular, the model is organised along a logical chain connecting the tower and the spire, the origin of ceramic artefacts (production centres), and the origin of raw materials (quarries), while also integrating the administrative location of the entities. As a summary, Table 8 presents the relationships considered within the system and their informational meaning.

Figure 38 shows the Entity-Relationship (E-R) diagram of the system, including the main attributes of the entities and the cardinalities adopted for each relationship. The cardinalities represented in the diagram express the reference conceptual model; the ways in which these relationships are currently implemented in the database – through foreign keys, relationship tables, and constraints – are described in the following paragraph.

Within the dataset considered, the relationship between tower and spire is modelled

as a one-to-one association (1;1 ↔ 1;1), since each tower is associated with a single spire and each spire belongs to a single tower. The relationship between spire and production centre is defined as (1;N ↔ 0;N): each spire is linked to at least one production centre, while a production centre may not be associated with any spires in the analysed sample, for instance if it is not documented for this specific type of artefact. Similarly, the relationship between production centre and quarry is modelled as (1;N ↔ 1;N), as each production centre must necessarily source materials from at least one quarry, and each quarry is associated with at least one production centre within the considered system. With regard to the territorial framework, the relationship between tower and municipality is defined as (1;1 ↔ 0;N): each tower is located within a single municipality, while a municipality may include a variable number of towers. Conversely, for production centres and quarries, the conceptual cardinality with respect to the municipality is defined as (1;N ↔ 0;N), since the same production or extraction context may fall – in different periods or following administrative redefinitions – within the boundaries of multiple municipalities. However, at the current stage, this relationship is not implemented through bridge tables, as the historical territorial extent cannot always be

Table 7. Entities of the information system, including primary keys, main attributes and geometry data management.

Entity	Primary Key	Attributes	Geometry data management
Tower	tower_id	building_type; denominatio; other_denominations; tower_label; municipality_istat; locality; address; construction_period; tower_definition; part_of_tower_system; tower_function; relative_position; access; plane_shape; max_plan_dimensions_m; height_m; number_of_level; tapering; width_to_height_ratio; structure_materials; sources_documentation; notes	Separate table (tower_points) linked via foreign key
Ceramic spire	spire_id	denomination; tower_id; tower_label; municipality_istat; current_status; spire_shape; ceramic_element_type; is_glazed; decorative_motif; color_scheme; number_of_colors; production_center_codes; construction_data; professionals_notes; bibliographic_sources; notes	Derived from associated tower
Production centre	production_center_id	code; name; municipality_istat; locality; activity_period; production_types; glazed_production; quarries_used; bibliographic_sources; notes	Separate table (production_center_points) linked via foreign key
Quarry	quarry_id	code; name; municipality_istat; locality; activity_period; quarry_type; material_types; exploitation_status; bibliographic_sources; notes	Separate table (quarry_points) linked via foreign key
Municipality	istat_code	name; province; population; area_kmq; capoluogo_regione; capoluogo_provincia; geom	Geometry field stored within the table

Table 8. Conceptual relationships among the entities of the information system.

Relationship	Description	Entities involved
Belonging	Identification of the tower to which the spire belongs	Tower – Spire
Origin of the ceramic element	Identification of the production centre from which the ceramic elements of the spire were produced.	Spire – Production centre
Origin of the raw material	Identification of the quarry from which the raw material for ceramic production was extracted	Production centre – Quarry
Territorial location	Identification of the municipality in which the production centre is located	Production centre – Municipality
Territorial location	Identification of the municipality in which the quarry is located	Quarry – Municipality
Territorial location	Identification of the municipality in which the tower is located	Tower – Municipality

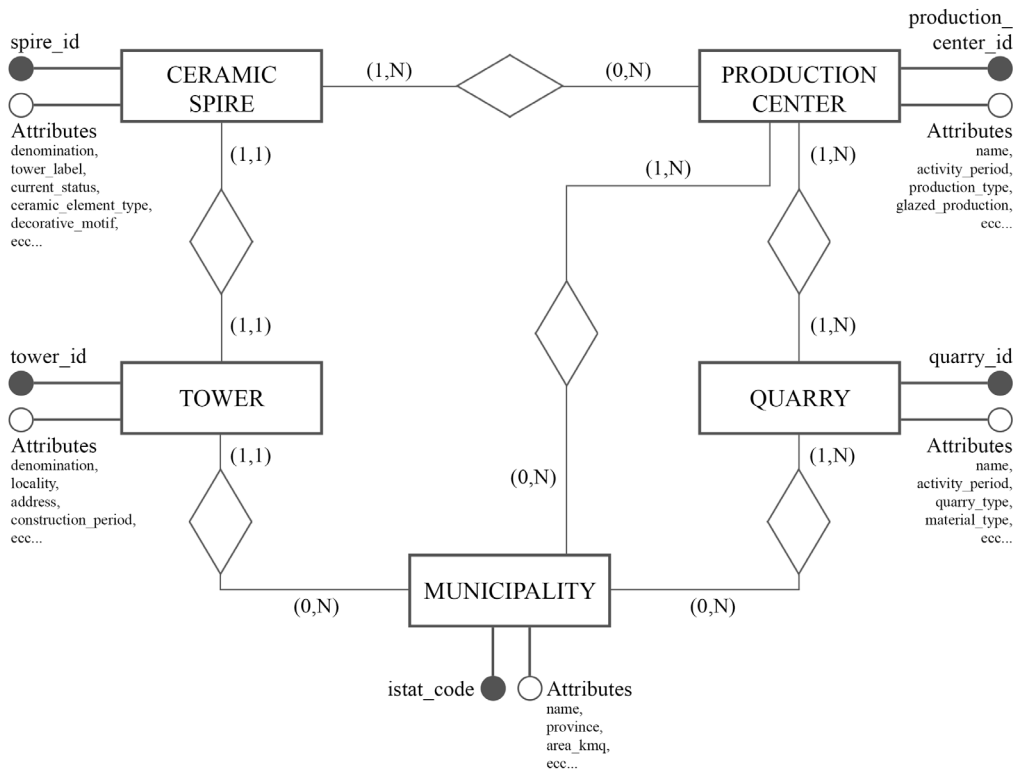


Figure 38. Entity-Relationship (E-R) diagram of the database, showing entities, main attributes and conceptual cardinalities.

reconstructed with sufficient accuracy; therefore, location is managed as point-based, associating each record with a reference municipality.

The conceptual relationships described in the previous paragraphs are implemented in the database through foreign keys, relationship tables, and integrity constraints. This approach allows the normalised structure of the entities to be maintained, recording associations without data duplication.

The relationship between tower and spire (1;1 \leftrightarrow 1;1) is implemented through a foreign key in the spires table (field tower_id) referencing the primary key tower_id in the towers table. The uniqueness of the association is ensured through a UNIQUE constraint applied to the field spires.tower_id, so that a single tower cannot be linked to multiple spire records. It should be noted that the field spires.tower_id is not defined as NOT NULL; however, within the dataset considered, the association is present for all records.

The relationship between spires and production centres (1;N \leftrightarrow 0;N) is implemented through the relationship table rel_spire_production_center, which allows multiple associations between the two entities to be recorded. The table contains two foreign keys (spire_id and production_center_id) and is defined by a composite primary key on these fields; both attributes are NOT NULL. This solution ensures the uniqueness of each spire-production centre pair and prevents duplication of associations.

The link between production centres and quarries (1;N \leftrightarrow 1;N) is implemented through the relationship table rel_production_center_quarry, structured similarly to the previous one, with two foreign keys referencing production_centers and quarries, a composite primary key, and NOT NULL fields. In this case as well, the composite key guarantees the uniqueness of centre-quarry pairs.

The territorial classification of towers is implemented through a foreign key in the towers table (field municipality_istat) referencing the field istat_code in the municipalities table. For production centres and quarries, the relationship with municipalities has not been modelled as a multiple association, as in several cases the historical territorial extent or the exact position with respect to current administrative boundaries cannot be reconstructed with sufficient precision. Consequently, these entities have been georeferenced as points falling within a municipality, privileging an operational administrative location over a historically uncertain modelling of plurality.

Table 9 summarises the specifications of the relationships between entities and their implementation within the database.

The geometries of point-based entities (towers, production centres, and quarries) are stored in dedicated tables derived from GIS layers (towers_points, production_centers_points, quarries_points), separate from the descriptive tables. Since these tables possess their own identifiers, the association between geometric and descriptive components is reconstructed through dedicated views (vw_towers, vw_production_centers, vw_quarries), used to generate complete layers within the GIS environment.

The consistency of recurring descriptive values is managed through lookup tables, organised according to a uniform structure consisting of an id field (integer, primary key) and a code field (text, NOT NULL) subject to a UNIQUE constraint. Lookup tables function as normalised repositories for the adoption of controlled vocabularies (e.g.

type of ceramic element, decorative motif, spire shape, tower function, etc.), reducing terminological ambiguity and facilitating data analysis. In the current model, these tables are not linked to entities through foreign keys but are used as reference systems for value encoding.

The defined relational structure represents an interpretative tool through which the relationships between artefact, production, and territory can be systematically reconstructed. The explicit description of the transition from the conceptual model to its implementation in the database – made visible through the E-R diagram and the description of implementation methods – ensures consistency between the theoretical framework and the operational management of data. The resulting information system enables a multi-level reading of the analysed heritage, integrating architectural dimension, production context, and territorial framework, and provides the basis for subsequent spatial and morphological analyses.

Table 9. Implementation of relationships within the database schema.

Relationship	Cardinality	Implementation method	Tables involved	Main constraints
Tower – Ceramic spire	(1;1 ↔ 1;1)	Foreign key + UNIQUE constraint	spires → towers	UNIQUE on spires. tower_id
Ceramic spire – Production centre	(1;N ↔ 0;N)	Junction table	rel_spire_production_center	Composite PK (spire_id, production_center_id), NOT NULL
Production centre – Quarry	(1;N ↔ 1;N)	Junction table	rel_production_center_quarry	Composite PK (production_center_id, quarry_id), NOT NULL
Tower – Municipality	(1;1 ↔ 0;N)	Foreign key	towers → municipalities	FK municipality_istat → istat_code
Production centre – Municipality	(1;N ↔ 0;N)	Foreign key	production_centers → municipalities	FK municipality_istat → istat_code
Quarry – Municipality	(1;N ↔ 0;N)	Foreign key	quarries → municipalities	FK municipality_istat → istat_code

7.2 - Integration within the GIS Environment and Construction of the Territorial System

The implementation of the relational model in PostgreSQL/PostGIS was integrated within the QGIS environment. This integration enabled the operational use of the information system on a territorial basis, translating the relational database structure into a cartographic system that can be queried and analysed.

The vector layers managed within the GIS environment derive from the views generated in the database (*vw_towers*, *vw_spires*, *vw_production_centers*, *vw_quarries*), which recombine the previously separated alphanumeric and geometric components. Management through views allows the database structure to remain distinct from its spatial representation, ensuring consistency between data updates and cartographic output, avoiding duplication, and maintaining alignment between descriptive and geometric information. From the perspective of spatial representation, towers, production centres, and quarries are modelled as point entities, while municipalities are represented as polygon entities and constitute the territorial reference unit for analysis. Spires, which do not have an independent geometry within the relational model, are associated with the location of their corresponding tower and are visualised in the GIS environment as a point layer through a dedicated view.

The reference coordinate system adopted for the entire project is RDN2008 / UTM zone 33N (EPSG:6708), in accordance with current regulations and selected for its suitability for the representation and metric analysis of the Sicilian territory. Layers derived from different sources – the ATA 2013 orthophoto of the Sicilian Region (EPSG:3857) and the municipalities layer acquired through the ISTAT plugin (EPSG:32632) – were reprojected into a common system to ensure spatial consistency and accuracy in distance and area calculations. The ATA 2013 orthophoto provided the cartographic base for the preliminary phase of identification and geolocation of spires; the resulting geometries were subsequently integrated into the database, becoming an integral part of the territorial information system.

This framework facilitates filtering operations, thematic classification, category-based statistics, and spatial analyses, forming the basis for the construction of the territorial system and for the typological and spatial-metric analyses presented in the following paragraphs.

Typological Analyses

Distribution of Towers by Province

The distribution of towers was analysed starting from the provincial attribute associated with municipalities, using category-based statistical operations within the GIS environment. Through this procedure, the number of towers falling within each provincial context was calculated, producing a summary table of absolute values. The results were subsequently used to construct a thematic map at a supra-municipal scale. A point-based representation of the towers was produced, symbolised according to their provincial affiliation, to make the spatial distribution of the structures within individual

territorial contexts clearly legible. In parallel, the provincial polygon layer was classified according to the number of towers using the Quantile method (equal count), in order to ensure a balanced distribution of cases across the thematic classes (Figures 39-41).

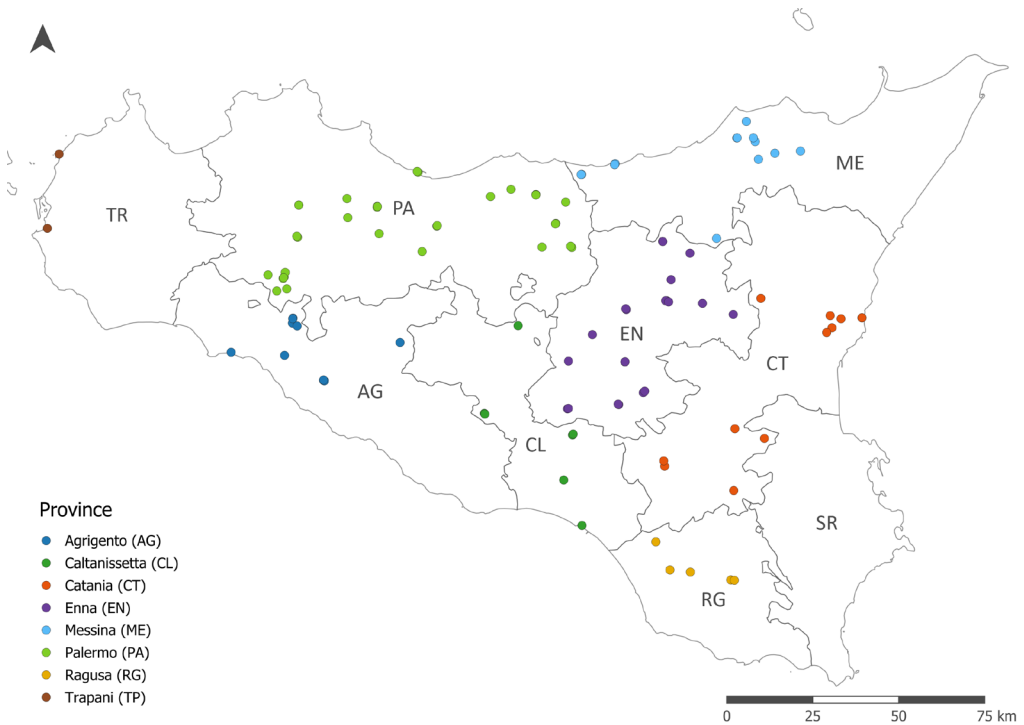


Figure 39. Spatial distribution of surveyed towers, with symbols categorised by province (the figure shows the result of spatial queries performed in QGIS).

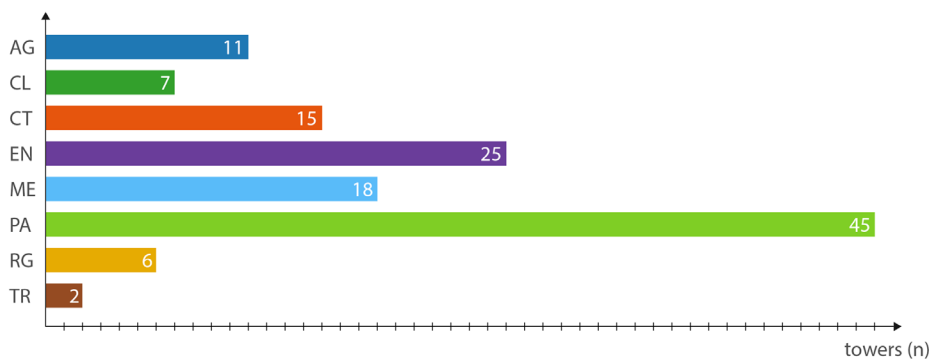


Figure 40. Chart showing the distribution of towers by province.

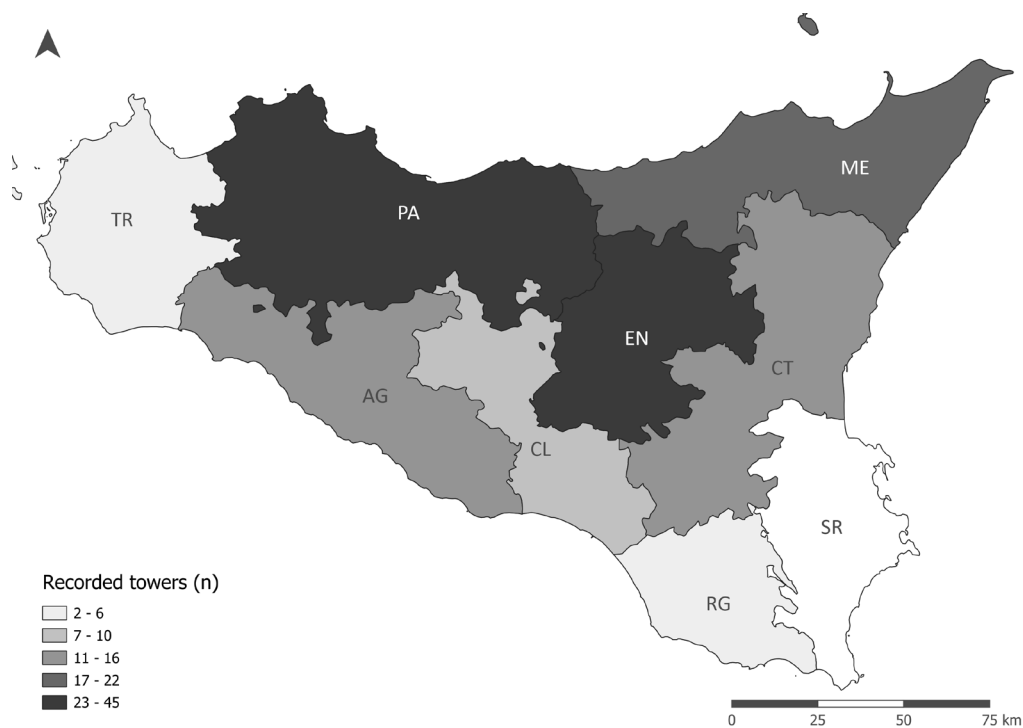


Figure 41. Provincial distribution of towers recorded in the database. Classification carried out using the Quantile method (equal count) in QGIS.

Classification of Spires by Type of Ceramic Element

The analysis was carried out based on the spire entity, considering the `ceramic_element_type` attribute, which identifies the type of ceramic element used in the construction of the roof covering. All spires included in the database were considered, regardless of their state of conservation, in order to provide an overall overview of the documented construction solutions. In cases where the typology could not be determined based on the available sources, the category unknown was retained, corresponding to undocumented data. The typologies included in the dataset comprise:

- wedge-shaped bricks, also referred to as *bugnette* or *zoccoli* (`wedge_brick`);
- shingles or scales (`shingle`);
- tiles (`tile`);
- mixed solutions, i.e. combinations of multiple types (`mixed`);
- undetermined cases (`unknown`).

Within the GIS environment, a categorised symbology was applied to the spire layer using `ceramic_element_type` as the classification field. The resulting point-based representation allows the visualisation of the territorial distribution of the different ceramic solutions, highlighting possible recurrences or typological concentrations (Figures 42-43).

Existing Wedge-Brick Spires Classified by Shape

The analysis was conducted by selecting a subset of the spires included in the da-

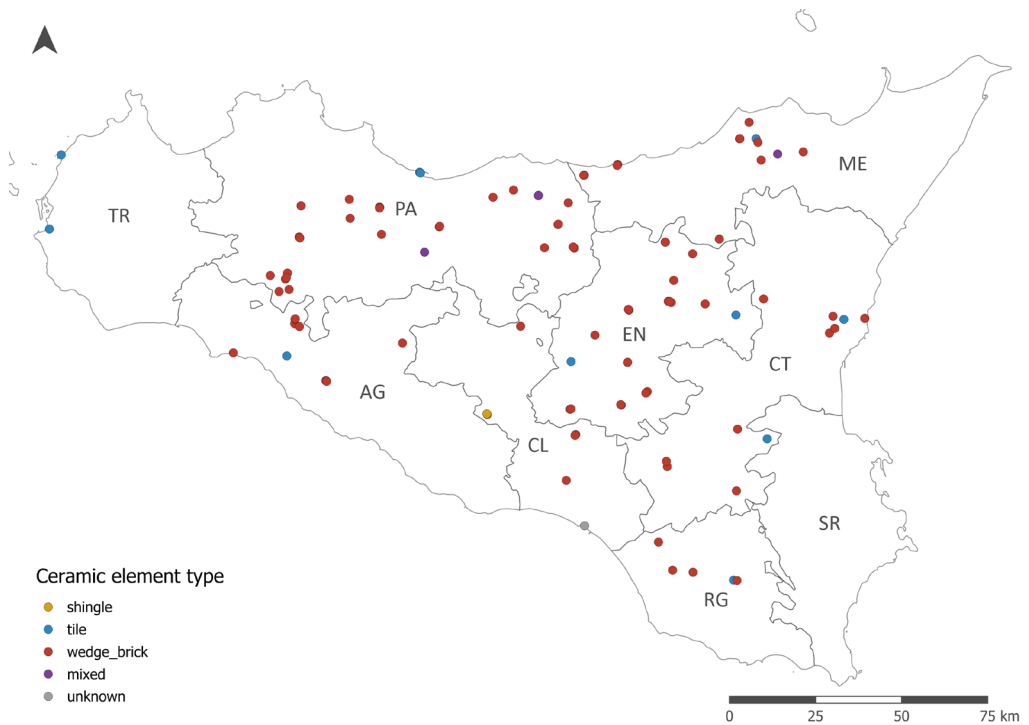


Figure 42. Spatial distribution of recorded spires, with symbology categorised according to the type of ceramic element used (the figure shows the result of spatial queries performed in QGIS).

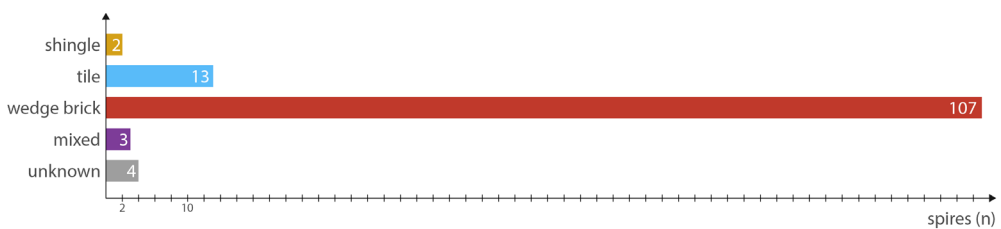


Figure 43. Number of recorded spires by type of ceramic element.

tabase, restricting the observation to existing cases constructed with wedge-shaped bricks. The filter was applied within the GIS environment through an attribute query on the `ceramic_element_type` field, selecting the category corresponding to wedge-shaped bricks, and on the `current_status` field, including only cases classified as existing. The resulting layer was subsequently classified according to the `spire_shape` attribute, which describes the morphological configuration of the roof. The forms documented within the considered subset include: bulbous, conical, double-curvature, hemispherical, hipped, octagonal or square pyramidal, and mixed-profile. A categorised symbology was then applied in order to visualise the territorial distribution of the different formal solutions. This representation makes it possible to relate the specific construction typology (wedge-shaped bricks) to the adopted geometric configurations, highlighting possible recurrences or territorial variations within the analysed sample (Figures 44-45).

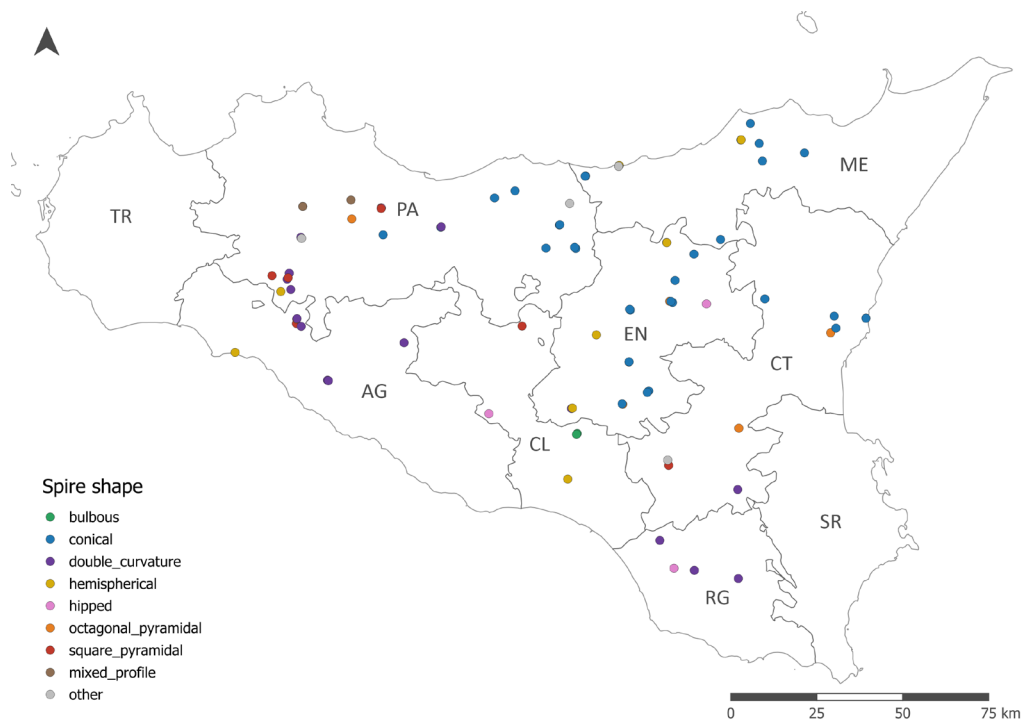


Figure 44. Territorial distribution of existing wedge-brick spires, classified according to morphological configuration (spire_shape) (the figure shows the result of spatial queries performed in QGIS).

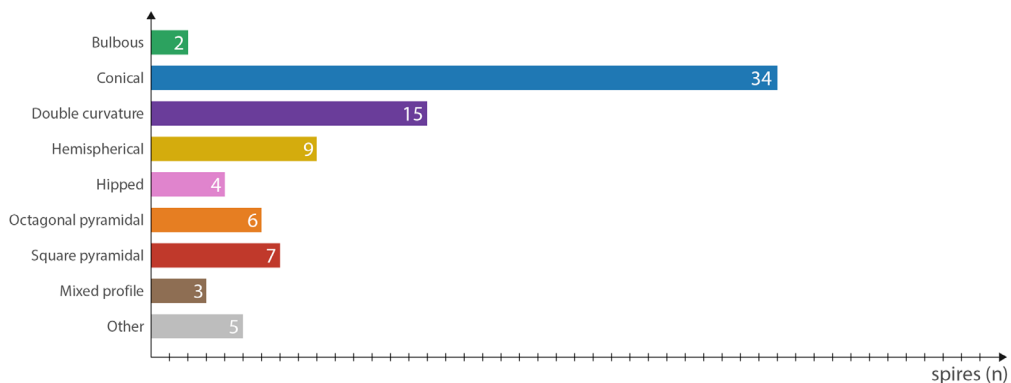


Figure 45. Numerical distribution of existing wedge-brick spires, classified by shape.

Existing Conical Wedge-Brick Spires Classified by Decorative Motif

The analysis was conducted by selecting a further subset of the spires included in the database, restricting the observation to existing cases constructed with wedge-shaped bricks and characterised by a conical shape (spire_shape = conical). The choice to focus on conical spires is motivated by their greater recurrence within the sample, which makes them typologically representative for comparative analysis. The filter was applied within the GIS environment through an attribute query on the ceramic_element_type, current_status, and spire_shape fields, isolating only the spires that meet the defined cri-

teria. For the identified sample, the `decorative_motif` attribute was considered, describing the ornamental pattern of the ceramic surface. The categories documented within the analysed subset include geometric patterns with horizontal bands, vertical bands, zig-zag patterns, spiral patterns, mixed compositions, and monochromatic fields; additionally, cases with unidentifiable motifs are also included. The resulting layer was classified using categorised symbology based on the decorative motif, enabling the visualisation of the territorial distribution of the different ornamental solutions associated with conical wedge-brick spires (Figures 46-47). This representation relates formal configuration and construction typology to decorative choices, highlighting possible recurrences or specific characteristics within the analysed sample.

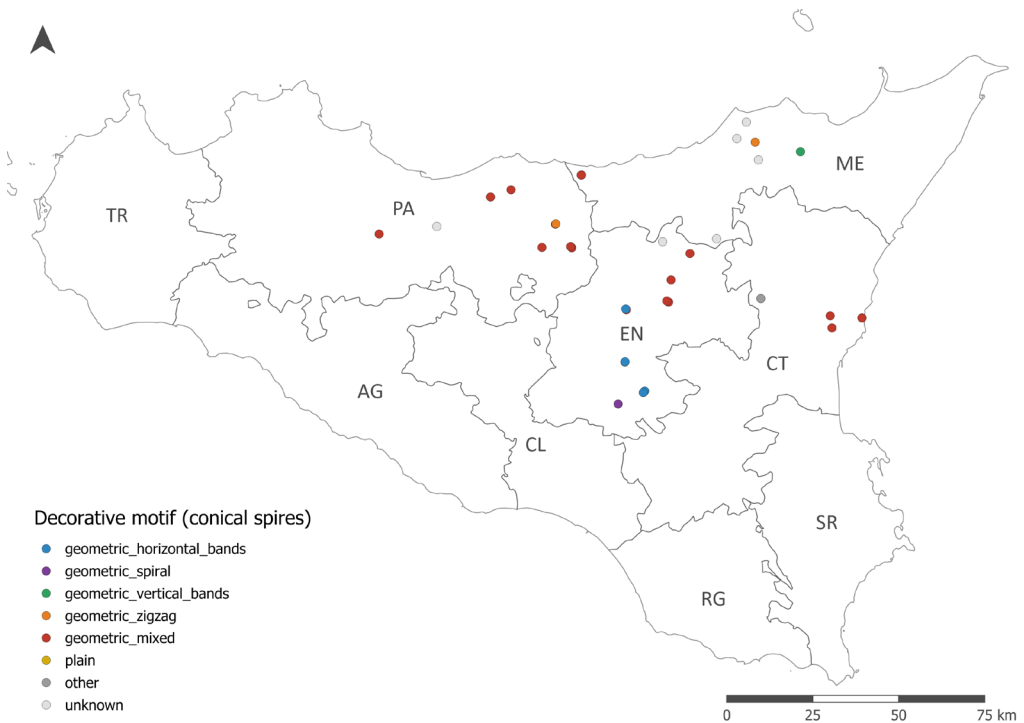


Figure 46. Spatial distribution of existing conical wedge-brick spires, classified according to decorative motif (the figure shows the result of spatial queries performed in QGIS).

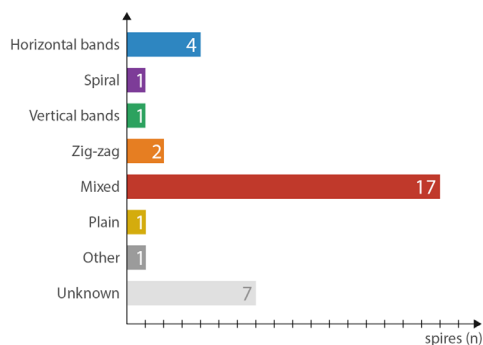


Figure 47. Numerical distribution of existing conical wedge-brick spires by decorative motif.

Overall, the typological and distribution analyses highlight several recurring trends in the configuration and territorial distribution of ceramic spires. The distribution of recorded towers is not uniform across the regional territory but shows a higher concentration in certain provinces, particularly Palermo and Enna, while other areas, such as the province of Siracusa, present no documented cases. This uneven distribution suggests differentiated historical and construction dynamics across the Sicilian territory. From this perspective, it is possible to hypothesise that certain catastrophic events have contributed over time to modifying the presence of these structures. In particular, the 1693 Val di Noto earthquake, which affected much of south-eastern Sicily causing the destruction of numerous urban centres, and the 1908 Messina earthquake may have influenced the preservation of towers and their ceramic roof coverings, contributing to the reduced presence of documented cases in some areas of the island.

From a morphological perspective, the analysis highlights a clear predominance of conical spires, followed by those with double curvature. This distribution may also be interpreted in light of construction logics related to the use of wedge-shaped bricks. The conical geometry is particularly suited to the use of wedge-shaped bricks not only as surface cladding but also as structural elements of the roof, whereas more complex forms – such as bulbous shapes or those with articulated curvature – tend to require more hybrid construction solutions and the use of wedge-shaped bricks exclusively as cladding.

The analysis of decorative motifs, conducted on conical spires, also reveals a predominance of mixed geometric compositions. This solution appears to combine greater expressive articulation with more flexible construction management of the conical surface, allowing variations in the pattern along the vertical development of the spire. The interruption and variation of decorative motifs between different horizontal registers facilitate the accommodation of construction adjustments – such as the progressive reduction in the number of elements per course – making them less perceptible.

Taken together, these observations contribute to outlining a relatively coherent typological framework in which formal choices, construction logics, and decorative solutions are closely interconnected.

Analysis of the Relationship Between Spires and Production Centres

In order to further investigate the territorial relationship between spires and ceramic production centres, a metric spatial analysis was carried out to quantify the distances between the artefacts and the documented production hubs. The analyses were organised into three successive phases: an initial assessment of the distribution of spires according to documented production centres; a second phase focused on calculating the linear distance between spires with known production centres and their corresponding production hubs; and a third phase aimed at defining proximity areas (buffers) around spires without documented production attribution, in order to identify potentially compatible centres in terms of distance.

First, the distribution of existing wedge-brick spires was analysed according to documented production centres, to highlight the relative weight of the different production hubs within the considered sample. The analysis was conducted by selecting a subset of

spires from the database, restricting the observation to existing cases constructed with wedge-shaped bricks. The filter was applied in the GIS environment through an attribute query on the *ceramic_element_type* and *current_status* fields, selecting respectively the category corresponding to wedge bricks and the cases classified as existing. For the selected spires, the link with the production centre entity was considered, reconstructed through the relationship implemented in the database between spires and production hubs. Within the GIS environment, this association was obtained through a join between the filtered spire layer and the relationship table, assigning to each case the documented production centre. The production centres identified within the analysed sample are: Burgio, Caltagirone, Collesano, Gangi, Naso, and Santo Stefano di Camastra. In one specific case, the use of elements originating from two different centres (Collesano and Santo Stefano di Camastra) is documented; this circumstance was retained as a distinct category in the classification to preserve the historical information without simplification. The cartographic representation was produced by applying categorised symbology based on the production centre, enabling the visualisation of the territorial distribution of production origins associated with existing wedge-brick spires (Figures 48-49).

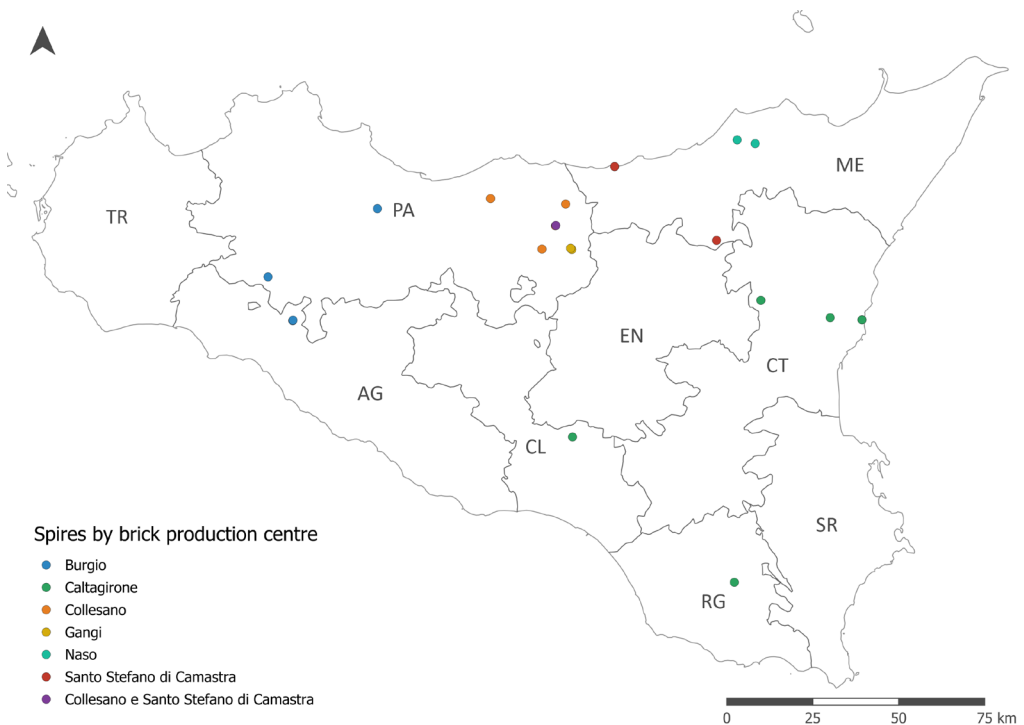


Figure 48. Spatial distribution of existing wedge-brick spires, differentiated according to documented production centre (the figure shows the result of spatial queries performed in QGIS).

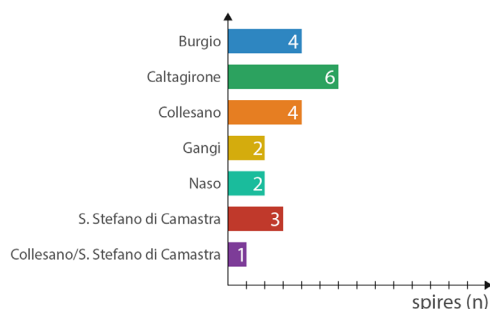


Figure 49. Number of existing wedge-brick spires by production centre.

For existing wedge-brick spires with a documented production centre, a linear distance analysis was carried out between each artefact and its corresponding production hub. The operation was performed in the GIS environment using the “Hub Lines” tool, generating a linear layer connecting each spire to its associated production centre. Distance calculations were carried out in the EPSG:6708 reference system (RDN2008 / ETRF2000), using metric units (Figure 50). Line lengths were initially expressed in metres and subsequently converted into kilometres for interpretative purposes. The maximum recorded distance within the analysed sample is 71.58 km, while the minimum is 0.15 km. This analysis makes it possible to quantify the territorial extent of the relationships between production and architectural use, providing a metric reference for the subsequent definition of proximity thresholds (Table 10).

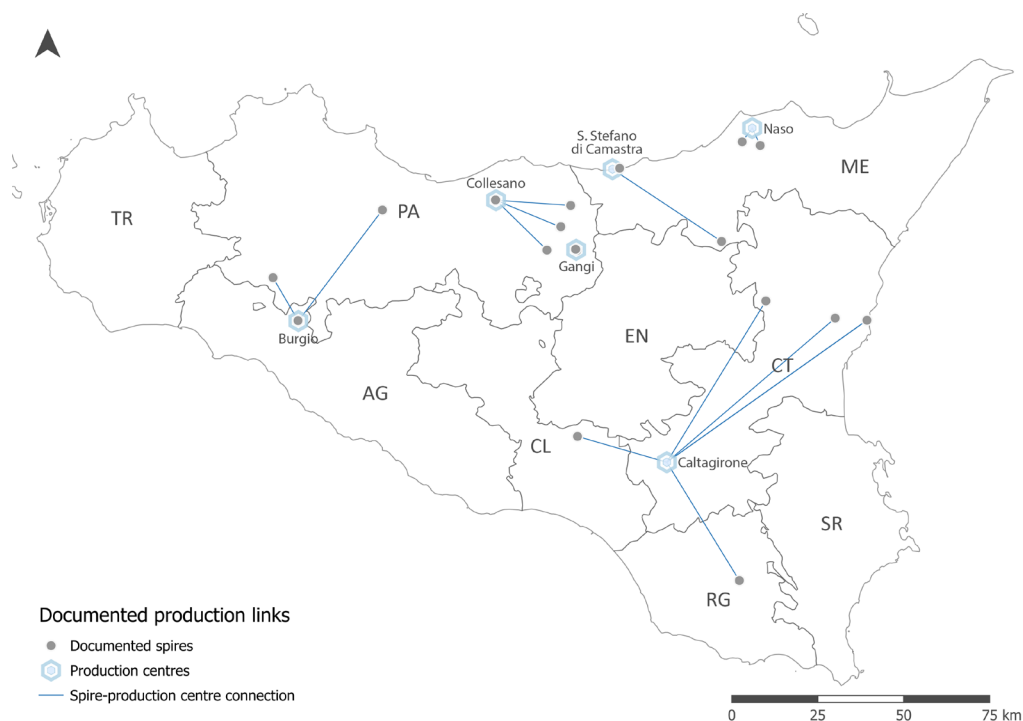


Figure 50. Linear connections between existing wedge-brick spires and their documented production centres (the figure shows the result of spatial queries performed in QGIS).

Table 10. Extract of distances between spires with documented production centres and their corresponding production hubs. Values were calculated as linear distances between the tower location and the production centre.

Production centre	Spire name	Spire municipality	Distance [km]
Burgio	San Giuseppe	Burgio	0.2
Burgio	Beata Maria Vergine Immacolata	Burgio	0.2
Burgio	San Giovanni Battista	Ciminna	40.7
Burgio	Santa Maria del Bosco	Contessa Entellina	14.7
Caltagirone	San Giuseppe	Mazzarino	27.1
Caltagirone	Maria Santissima Annunziata	Acireale	71.6
Caltagirone	Maria Santissima Annunziata	Acireale	71.6
Caltagirone	San Pietro	Adrano	55.4
Caltagirone	Santa Caterina Alessandrina	Pedara	64.7
Caltagirone	San Vincenzo Ferreri	Ragusa	40.6
Collesano	Santa Maria la Vecchia	Collesano	0.2
Collesano	Santo Stefano	Geraci Siculo	20.3
Collesano	Santa Maria di Loreto	Petralia Soprana	20.8
Collesano	San Mauro Abate	San Mauro Castelverde	21.8
Gangi	San Cataldo	Gangi	0.3
Gangi	Santissimo Salvatore	Gangi	0.2
Naso	Santa Barbara	Castell'Umberto	5.6
Naso	Santi Alfio, Cirino e Filadelfo	Mirto	5.0
Santo Stefano di Camastra	Chiesa di Borgo Giuliano	San Teodoro	38.2
Santo Stefano di Camastra	Del Calvario	Santo Stefano di Camastra	2.1
Santo Stefano di Camastra	Del Calvario	Santo Stefano di Camastra	2.1

For wedge-brick spires lacking documented production attribution, a proximity analysis was carried out in order to identify potential production centres compatible in terms of distance. To this end, concentric buffers were generated around the documented production centres, using distance thresholds of 5 km, 24 km, 48 km, and 72 km (Figures 51-52). The minimum threshold of 5 km was assumed as an intra-municipal proximity distance, while the maximum threshold of 72 km corresponds to the maximum distance recorded in the previous analysis (71.58 km), thus constituting an empirical limit derived from the observed sample. The intermediate thresholds of 24 km and

48 km were defined by interpolation, to structure the analysis into progressive distance bands. The overlap between the buffers and the distribution of spires without known production centres allows a preliminary assessment of territorial compatibility between artefacts and production hubs, highlighting cases that fall within distance ranges comparable to those already documented for spires with confirmed attribution (Table 11).

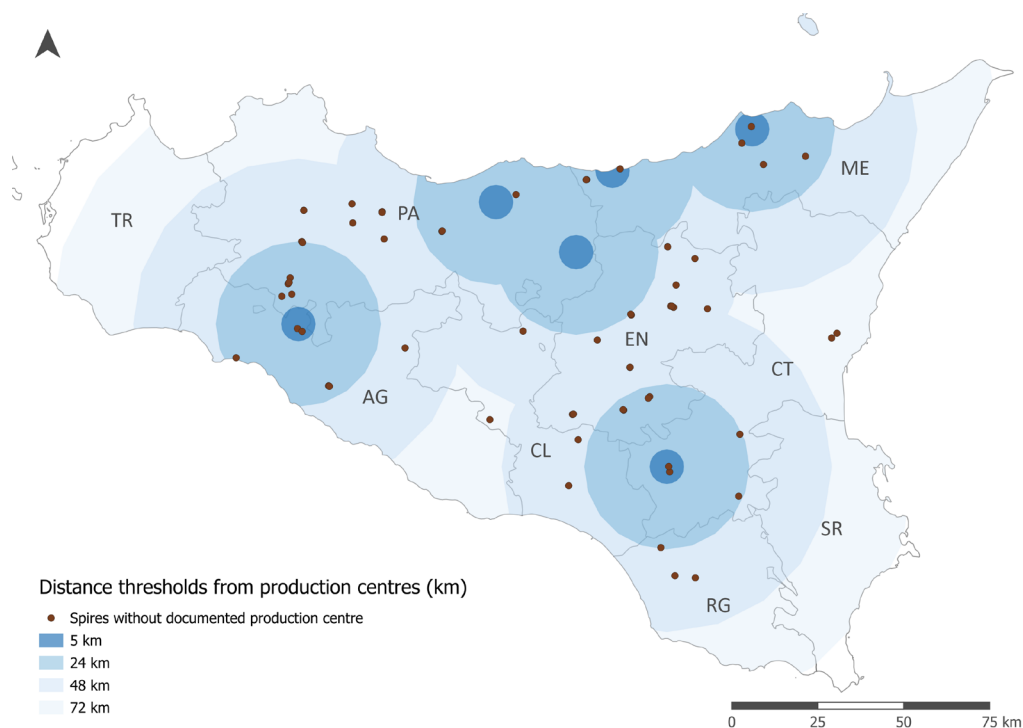


Figure 51. Proximity areas generated around ceramic production centres (5, 24, 48, and 72 km) and distribution of wedge-brick spires without documented production attribution (the figure shows the result of spatial queries performed in QGIS).

Table 11. Number of wedge-brick spires without documented production attribution falling within the different distance thresholds (5, 24, 48, and 72 km) from the considered production centres. Values indicate the cumulative number of cases within each proximity band. A single spire may fall within the proximity thresholds of multiple production centres.

Production centre	≤ 5 km	≤ 24 km	≤ 48 km	≤ 72 km
Burgio	2	12	21	25
Caltagirone	2	9	24	32
Collesano	0	3	12	43
Gangi	0	2	25	41
Naso	1	4	8	20
Santo Stefano di Camastra	1	3	16	31

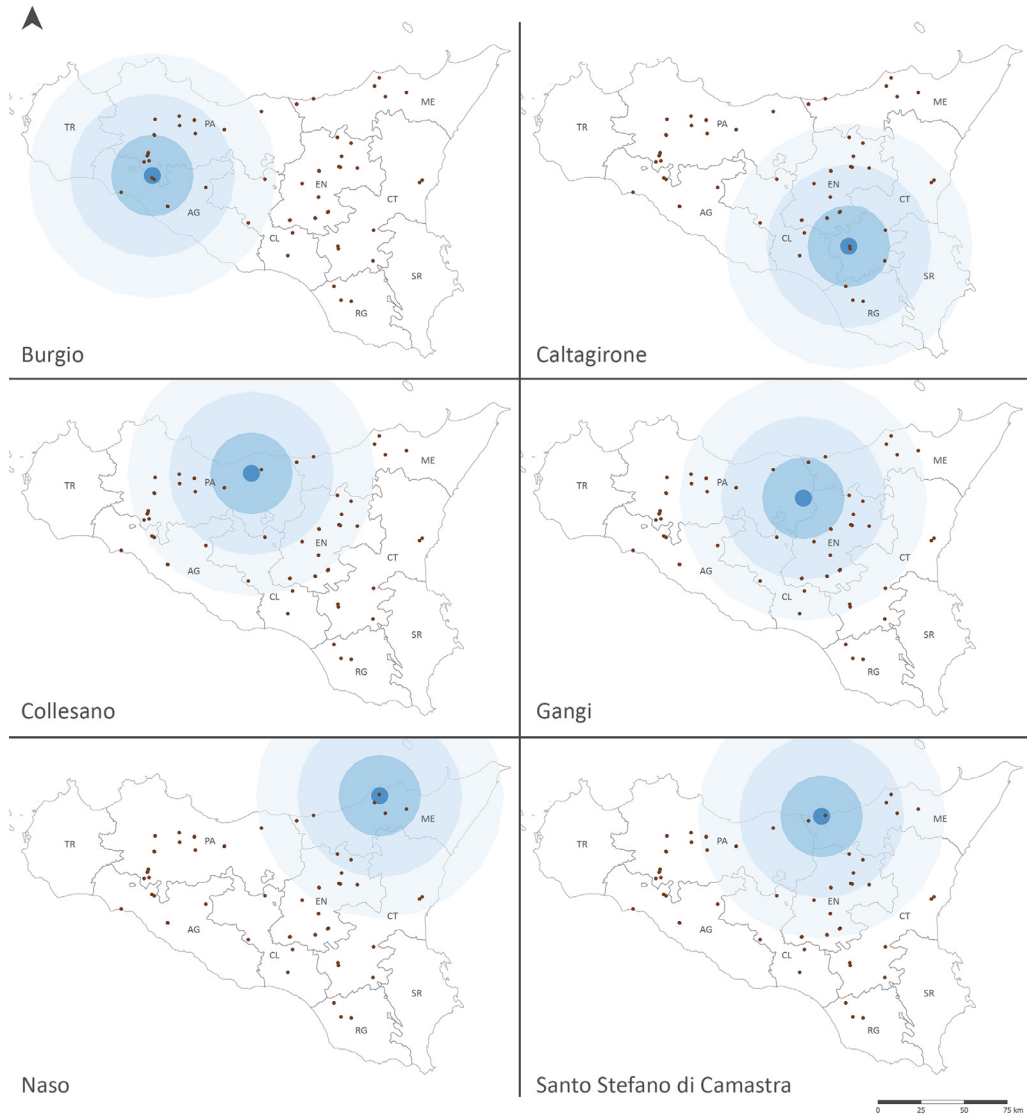


Figure 52. Proximity analysis by individual production centre. The maps show distance thresholds (5, 24, 48, and 72 km) around the different production hubs and the distribution of wedge-brick spires without documented attribution (the figure shows the result of spatial queries performed in QGIS).

Overall, the metric analyses enable the identification of several recurring patterns in the relationships between towers with ceramic spires and the production centres of wedge-shaped bricks. The distance analysis for cases with documented production centres shows that the connections between architectural artefacts and production hubs do not generally remain confined to a strictly local scale, but may extend over considerable distances, exceeding 70 km. The proximity analysis conducted on spires without production attribution provides a preliminary assessment of territorial compatibility between artefacts and different production centres. The distribution of the analysed cases

shows that the shortest proximity thresholds (5 km and 24 km) include only a limited number of unattributed spires, suggesting that the distribution of these artefacts does not operate solely within a strictly local radius. The intermediate threshold of 48 km appears to be the most significant for the majority of production centres (Burgio: 21 cases; Caltagirone: 24; Gangi: 25), thus defining a prevailing operational range. This finding suggests the existence of medium-scale distribution areas, within which the circulation of materials extends beyond the local scale while remaining confined within relatively circumscribed territorial contexts. The maximum threshold of 72 km further expands the potential distribution range, outlining areas of territorial compatibility at a sub-regional scale. The analyses also show that individual spires may fall within the proximity thresholds of multiple production centres simultaneously. This confirms that the adopted buffers do not represent areas of univocal attribution, but rather zones of territorial compatibility within which different centres could potentially have supplied the ceramic elements. In this sense, the analysis primarily contributes to defining a plausible territorial dimension of ceramic product circulation, rather than identifying with certainty the production centre of origin.

The analyses presented represent only a portion of the possible queries enabled by the developed information system, whose structure allows further processing and spatial analyses according to specific research needs.



Chapter 8 - Architectural Documentation and Case Study Analysis

This chapter examines the architectural documentation of the towers under study, shifting the scope of the investigation from the territorial dimension addressed in the previous chapter to the scale of the individual artefact. The aim is to investigate, through the analysis of a selection of representative case studies, the architectural and morphological characteristics of the towers and their ceramic coverings.

The chapter outlines the documentation methods adopted for the study of the selected towers, integrating cataloguing tools and digital survey techniques. The application of these tools makes it possible to systematically represent the architectural and material characteristics of both the towers and their spires, thus constructing a knowledge base to support subsequent interpretative and comparative analyses.

The chapter opens with the definition of the criteria adopted for the selection of the case studies; it then presents the operational tools employed for the documentation of the towers, namely the integrated survey protocol and the cataloguing documentation sheet. In the central part of the chapter, these tools are applied to the individual case studies. The final section is devoted to the construction of discrete Finite Element models to carry out preliminary assessments of the structural behaviour of the towers.

8.1 - Criteria for the Selection of Case Studies

The definition of the case studies was guided by the objective of conducting an in-depth analysis of selected towers characterised by the presence of spires clad in wedge-shaped bricks, a construction typology that constitutes the primary focus of this research. The analysed sample consists of towers located in the province of Catania, particularly in the area immediately south of Mount Etna, a territorial context in which this phenomenon is widespread and where it was possible to carry out direct documentation and survey activities on a continuous basis (Figure 53). Although confined within a relatively limited geographical area, the towers considered exhibit different characteristics in terms of spire configuration, structural dimensions and execution quality of the

◀ South spire of the Cathedral of Maria Ss. Annunziata in Acireale (CT).

ceramic coverings, thus offering a set of cases that are comparable while at the same time diversified from a morphological and constructive perspective.

Two of the analysed towers belong to the complex of the Cathedral of Maria Santissima Annunziata in Acireale and feature large conical spires, among the most significant within the provincial context. The tower of the Church of Santa Caterina in Pedara is distinguished by the greater slenderness of the structure and by the presence of a conical spire characterised by specific decorative solutions. The spire of the tower of the Church of Santa Maria delle Grazie in Tremestieri Etneo is smaller in scale and exhibits an overall simpler execution quality compared to the other analysed cases. Finally, the tower of the Church of San Pietro in Adrano has been included in the sample as it represents a case of a spire only partially clad in wedge-shaped bricks.

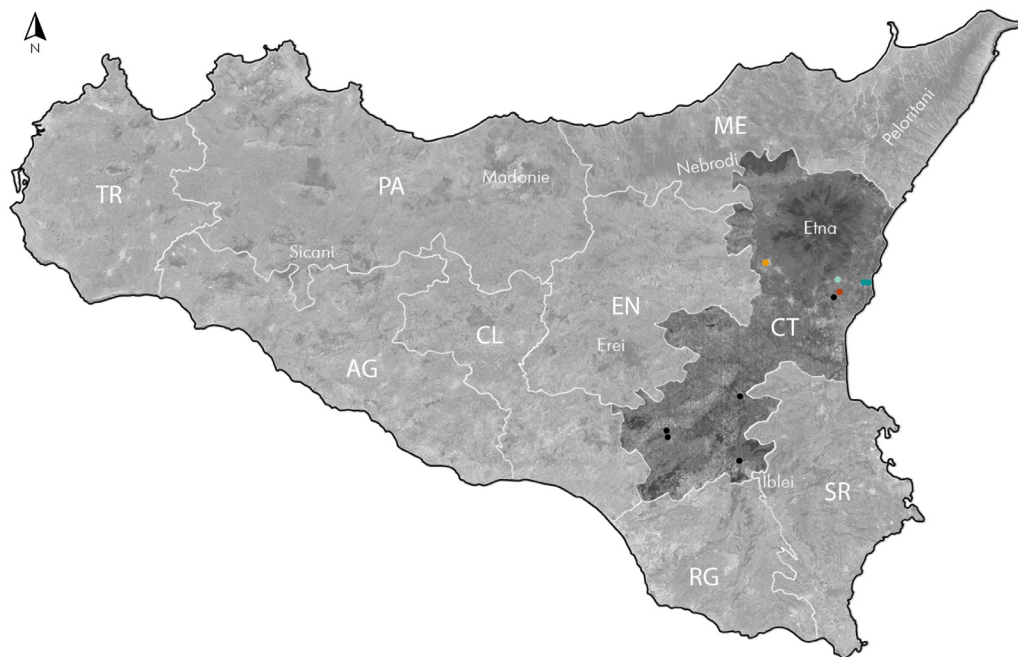


Figure 53. Selected case studies in the province of Catania.

Taken together, the selected towers constitute a limited yet significant sample for the analysis of ceramic spires in the Etnean area, allowing the observation of different morphological and constructive configurations within a relatively homogeneous territorial context.

8.2 - Integrated Survey Protocol

The survey of the analysed towers constitutes a fundamental phase within the documentation process developed in this research, as it enables the acquisition of accurate geometric and morphological information on the artefacts and their coverings. The three-dimensional representation of the towers makes it possible to describe in detail the architectural configuration of the structures and to document the characteristics of the ceramic spires, which represent the distinctive element of the phenomenon under investigation. Furthermore, the three-dimensional models derived from the survey constitute a knowledge base of relevance also in relation to the conservation and safeguarding of these artefacts. The availability of accurate geometric models allows for the recording of the current state of the structures and provides metric documentation useful for potential conservation interventions, monitoring activities, or further analyses, thereby contributing to the management and protection of these heritage assets against natural and human-induced risks. Within this context, survey activities aim to generate accurate three-dimensional models of the towers and their coverings. These models provide the basis for subsequent graphical outputs and analyses presented in the text, while also functioning as a digital archive and virtual record of a historical-architectural heritage at risk.

The geometric documentation of the towers was carried out through an integrated survey approach, based on the combined use of different three-dimensional acquisition techniques (Figures 54-55). The choice to adopt such a strategy was determined by the morphological characteristics of the towers under study, which exhibit considerable heights, complex volumetric articulations, and roof structures located in the uppermost parts of the buildings, which are difficult to document using a single survey technique.

The implemented workflow involved the use of point clouds acquired through Terrestrial Laser Scanning (TLS) as the reference dataset for the construction of the three-dimensional models, integrating these with data obtained from other acquisition systems depending on the characteristics of the sites and the different portions of the artefacts to be documented. In particular, TLS technology (P30 and BLK360 laser scanners by Leica Geosystems) was employed to survey both the internal and external spaces of the churches, acquiring high accuracy point clouds suitable for documenting the architecture of the buildings and the context in which the towers are located. The survey of the interiors of the bell towers was instead carried out using Mobile Laser Scanning (MLS) (BLK2GO by Leica Geosystems), which enabled the rapid acquisition of three-dimensional data along the vertical circulation paths of the towers and within more confined interior spaces (Table 12). The documentation of the upper portions of the towers was finally complemented through UAV-based digital photogrammetry using Structure-from-Motion techniques (DJI Mini 2), which made it possible to acquire

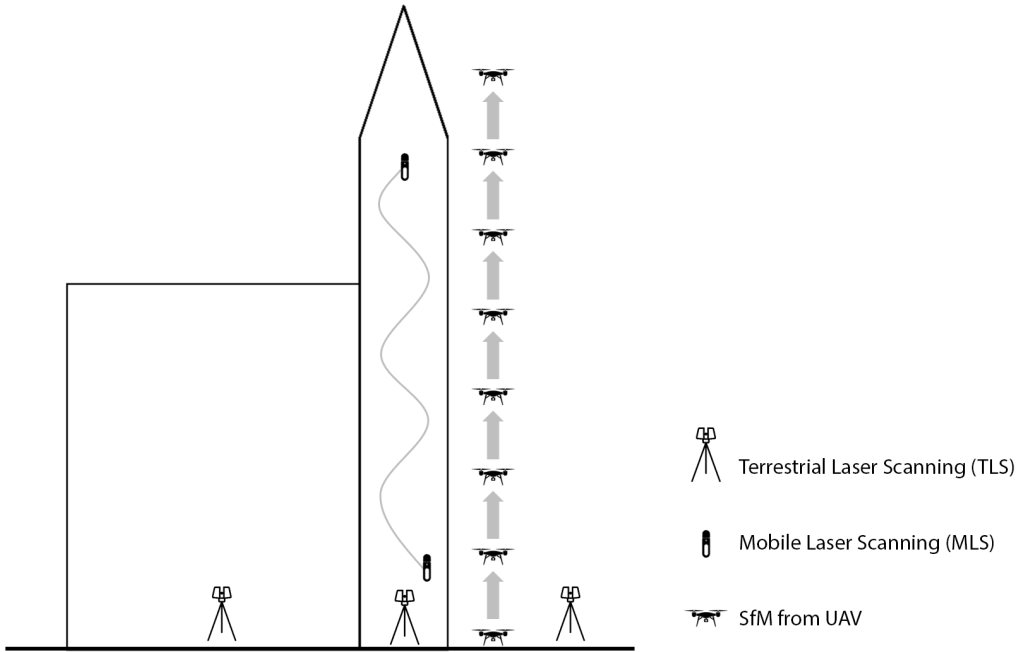


Figure 54. Diagram of the acquisition techniques used for the survey of the towers and their spires.

Table 12. Maximum range and nominal scanning speed of the laser scanners employed.

Laser scanner	Maximum Range [m]	Scanning Speed [points per second]
P30	270	1.000.000
BLK360	60	360.000
BLK2GO	25	420.000

images of the external surfaces of the towers and their spires, allowing the documentation of areas that are difficult to access from the ground.

The datasets acquired through the different survey techniques were subsequently processed through an integration workflow aimed at constructing complete three-dimensional models of the towers and their coverings. In an initial phase, the scans obtained through Terrestrial Laser Scanning (TLS) were registered and aligned within Cyclone Register (proprietary software by Leica Geosystems) to generate a unified point cloud, which was used as the geometric reference for subsequent integration operations. The data acquired through Mobile Laser Scanning (MLS) were then integrated with the TLS point clouds, allowing the completion of the three-dimensional documentation of the internal spaces of the towers. In parallel, the images acquired via UAV were processed through Structure-from-Motion (SfM) procedures within Agisoft Metashape software to generate three-dimensional models and orthophotos of the upper portions of the structures and of the spires.

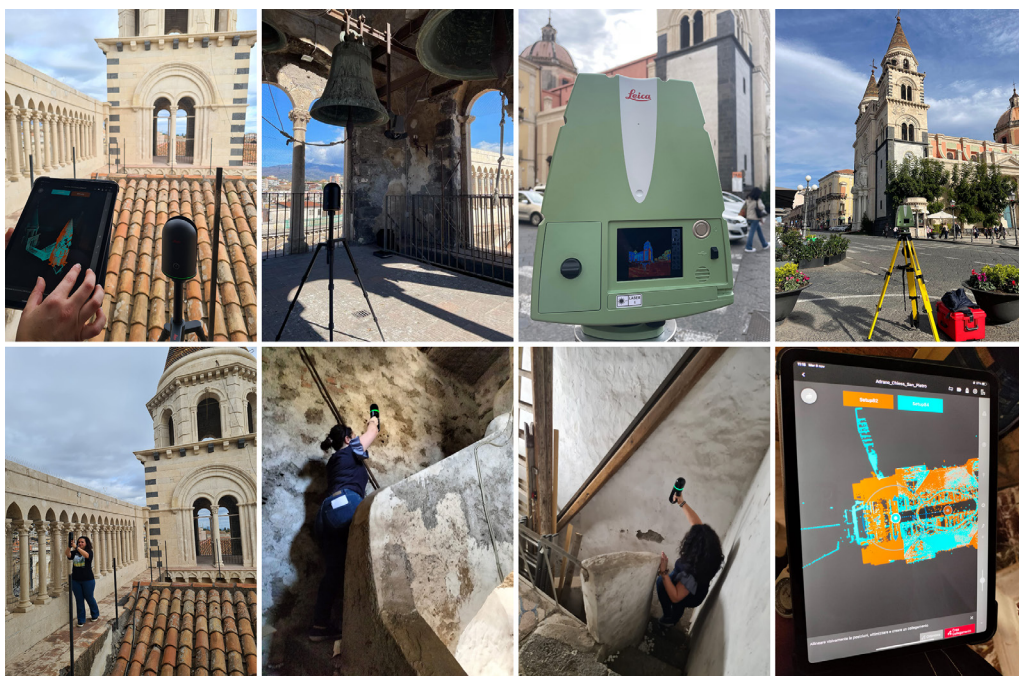


Figure 55. Data acquisition phases during the survey campaigns of the case studies.

8.3 - Survey and Architectural Documentation of the Case Studies

Based on the operational protocol described in the previous section, the five towers selected as case studies were subject to an architectural documentation process aimed at representing their main geometric, morphological, and constructive characteristics. The application of integrated survey techniques enabled the acquisition of complete three-dimensional models of the structures and their coverings, which were used as a basis to produce graphical outputs and for the compilation of the cataloguing documentation sheets. Each tower was analysed following a consistent interpretative framework, including the historical and architectural overview of the artefact, the analysis of the urban and landscape context, the description of the survey activities carried out, and the presentation of the outputs derived from the three-dimensional model.

The following sections therefore present the individual case studies, illustrating for each tower the adopted documentation methods and the main results obtained.

8.3.1 - The Towers of the Cathedral of Maria Santissima Annunziata in Acireale

Historical and Architectural Overview

The church dedicated to the cult of Maria Ss. Annunziata, now the Cathedral of the Diocese of Acireale, is located within the historic centre of the city, in correspondence with the main square that constitutes the focal point of urban life in the historic settle-



Figure 56. Location and urban context of the Cathedral of Maria SS. Annunziata in Acireale.

ment (Figure 56). This square is bordered not only by the Cathedral but also by some of the most important buildings in the city: the Basilica of Saints Peter and Paul, the Loggia Giuratoria (Town Hall), and several significant private palaces. The importance of this space reflects its historical role as a crossroads of the principal urban routes of the town since its origins: Corso Umberto, Via Currò, Corso Savoia, Via Camillo Benso Conte di Cavour, Via Davì, Via Vittorio Emanuele II, and Via Romeo.

The construction history of the Cathedral of Acireale (Li Rosi & Russo, 2024) dates back, according to some historical sources, to the fourteenth century. The Canon Vincenzo Raciti Romeo, reporting the words of Lo Bruno, states that in 1532 “si rifabbricò la nuova Chiesa in forma più grande col suo campanile [...]”¹, and that by 1544 the church appears enlarged and equipped with the first loggia of the bell tower, corresponding to the present-day south tower (Donato, 1976; Raciti Romeo, 1929). The latter was completed with the second and third loggia levels and a spire covered with polychrome bricks between 1719 and 1732 (Gravagno, 1989). In particular, in 1729 the construction of the south bell tower, designed by the architect Paolo D’Amico, was entrusted to Giovanni Flavetta and Francesco Guido, the latter being responsible for the production of the glazed wedge-shaped bricks (Bella & Grasso, 2012, p. 116).

In 1872, the church was elevated to Cathedral status and, four years later, the Ministry of Public Education declared the bell tower a monument of national significance. Between 1887 and 1890, the façade was constructed in its current form, based on a design

¹ Author’s translation: “the new small church was rebuilt in a larger form with its bell tower [...]”

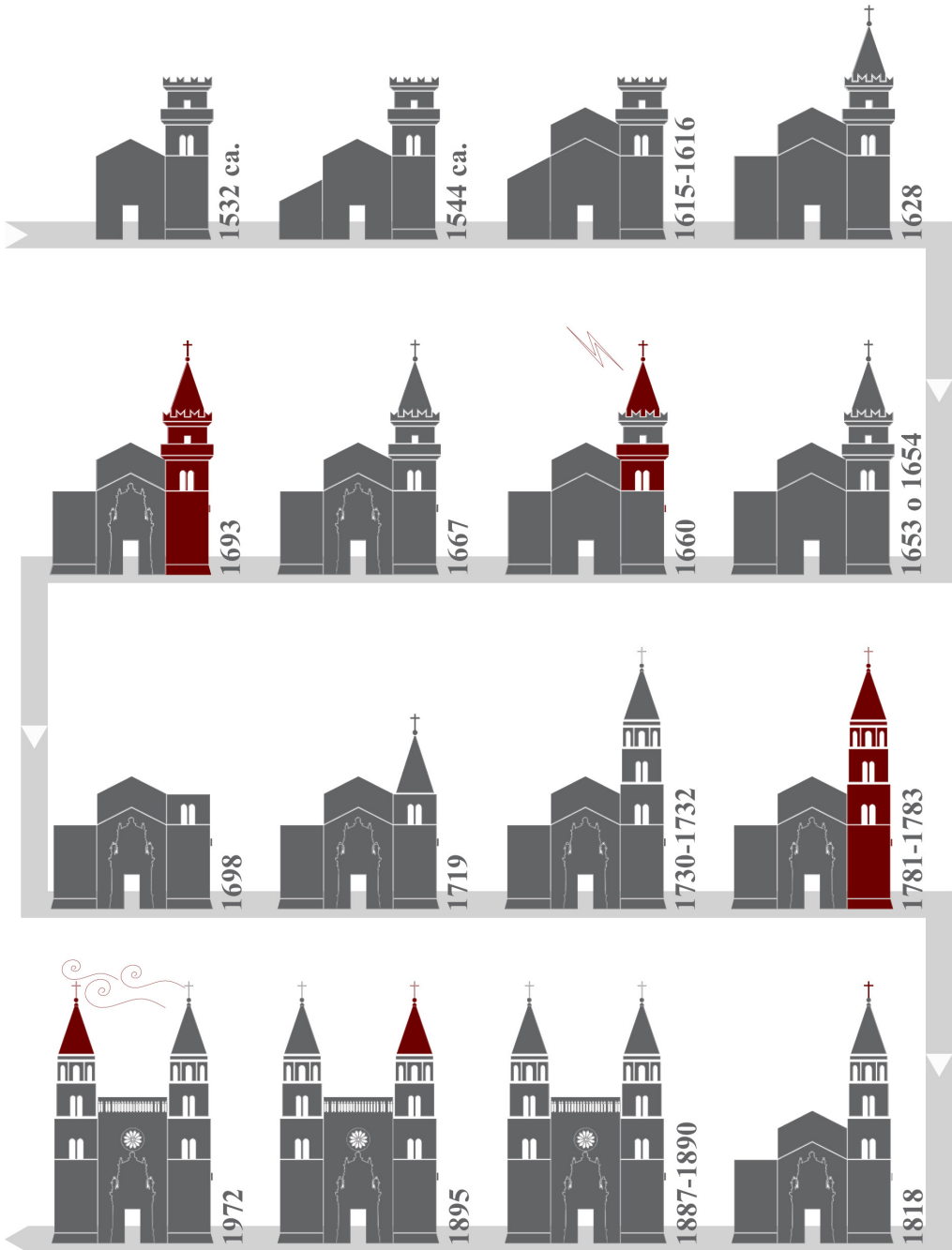


Figure 57. Schematic chronology of the construction phases of the Cathedral of Maria Ss. Annunziata in Acireale and its towers. Events involving damage to the structure are highlighted in red.



Figure 58. Details of the historical iconography of the city of Acireale. From left: *L'Angelo custode*, Antonio and Giacinto Platania, oil on canvas, 1630, Cathedral of Acireale; *Passaggio di Don Redin ad Acireale*, Giacinto Platania, 17th century, Biblioteca e Pinacoteca Zelantea, Acireale; *Veduta della città di Acireale dal mare*, Emanuele Grasso, c. 1820, Biblioteca e Pinacoteca Zelantea, Acireale; *Veduta della città di Acireale dal Piano dei Padri Carmelitani*, Emanuele Grasso, c. 1850, Biblioteca e Pinacoteca Zelantea, Acireale; *Veduta di Acireale da mare*, Paul Pennisi (1930–2018), Biblioteca e Pinacoteca Zelantea, Acireale.

by the architect Sebastiano Ittar with modifications by Giovan Battista Filippo Basile (Gravagno, 1989). During the same period, the north tower was also built, modelled on the pre-existing one (Figure 57).

The façade, as in many churches in the Catania area, displays a refined chromatic contrast resulting from the alternation between white stone and lava stone. It rests on a lava stone base and is composed of a central section, characterised by Neo-Gothic elements – including the rose window, the loggia with slender columns, and the main portal with sculptural decorations – and two lateral sections entirely occupied by the towers. The central section and the upper parts of the towers are built in white stone ashlar, while the corner elements of the towers are made of lava stone blocks.

The tripartite articulation of the main façade reflects the layout of the Latin-cross plan with three aisled naves terminating in apses. The central nave, covered by a barrel vault with lunettes, is interrupted at the crossing with the transept by a dome set on a circular drum; the side aisles, articulated into five bays each, are instead covered by groin vaults.

The south tower is composed of four storeys and houses both the bell system and the clock, while the north tower develops over three storeys. Both towers have an approximately square plan and feature, at the uppermost level, a conical spire made of glazed wedge-shaped bricks set on an octagonal drum.

The Towers of the Cathedral of Acireale in the Urban Landscape

The façade of the Cathedral, characterised by its soaring bell towers and Neo-Gothic stylistic elements, stands out clearly within the surrounding urban fabric. The building emerges in relation to the neighbouring architecture both due to the height of its towers and to its distinctive stylistic and formal features. Despite this evident difference, the presence of the Cathedral does not appear extraneous to the urban landscape, also in light of the strong symbolic and identity-related value it holds for the city².

The south bell tower and the imposing volume of the church, together with the other bell towers and domes of Acireale, are clearly recognisable within the relatively uniform

² This subsection is based on the interpretative framework proposed by author in Russo and Galizia (2024).

mass of the surrounding building roofs. This condition is already documented from the seventeenth century onwards in the historical iconography of the city, in which these architectural features appear as distinctive elements of the urban skyline (Figure 58). In this context, the spires clad in glazed wedge-shaped bricks contribute significantly to the recognisability of the towers within the urban landscape, enhancing their verticality and visibility in the city skyline.

Following the approach proposed by Kevin Lynch in *The Image of the City*, the analysis of the urban landscape can be conducted through the identification of a number of key elements that contribute to the construction of the image of the city (Lynch, 1964). Among these, particular relevance is assigned to paths, nodes, and landmarks, which represent some of the main components through which observers perceive and mentally organise urban space. Applying this interpretative model to the urban area in which the Cathedral of Acireale is located, it is possible to recognise a network of paths connecting the main nodes of the city and leading towards the principal square, where some of the most significant architectural features are concentrated. In this context, the Cathedral and its towers crowned by coloured spires assume the role of visual landmarks within the urban fabric, standing out from the surrounding roofs and contributing to the definition of the city skyline.

The analysis was carried out using as a comparative basis a selection of cartographic and iconographic representations of the city belonging to different historical periods, including the *Pianta scenografica della città di Aci Reale in Sicilia nella Valle di Demona* from the volume *Delle città d'Italia e sue isole adiacenti compendiose notizie sacre e profane* by Cesare Orlandi (1770), the maps of the Bourbon Cadastre preserved at the Archivio Mortillaro di Villarena (1837–1853), and current satellite imagery of the territory (Figure 59).

According to this reading, paths represent the main channels through which the observer moves within urban space and constructs their experience of the city. As the author states, “paths are the channels along which the observer customarily, occasionally, or potentially moves [...]. People observe the city while moving along them, and the other environmental elements are arranged and related along these paths” (Lynch, 1964, pp. 65-66). For this reason, they constitute, for most people, one of the most easily recognisable components of the urban environment.

In the case of the city of Acireale, the main paths can be identified in the streets leading towards the Cathedral square, the central node of the urban system. The analysis of visual sequences along these routes shows how at least one of the Cathedral bell towers is generally perceptible along the path, progressively appearing between the buildings that define the urban fabric. Conversely, along the routes extending towards the sea – behind the main church – the visibility of the towers is more limited, both due to the slope of the terrain and to the presence of narrow urban canyons determined by the configuration of the built fabric (Figure 60).

Alongside paths, Lynch's model also identifies nodes and landmarks, elements that contribute to the construction of the mental image of the city. Nodes are places of concentration and intersection of paths, while landmarks are point-based elements that are easily recognisable and allow observers to orient themselves within urban space (Lynch,



Figure 59. Identification of paths, nodes, and landmarks. Top: Pianta scenografica della città di Acireale in Sicilia nella Valle di Demona, print in *Delle città d'Italia e sue isole adiacenti compendiose notizie sacre e profane*, Cesare Orlandi, 1770. Middle: City of Acireale, Bourbon Cadastre, Archivio Mortillaro di Villarrena, 1837–53. Bottom: satellite image.

1964). In light of this interpretative framework, the Cathedral square can be understood as one of the main nodes of the urban system of Acireale, while the church towers assume the role of visual landmarks within the urban fabric. In this context, the spires clad in glazed wedge-shaped bricks contribute to strengthening the recognisability of the towers, making them easily identifiable elements within the urban landscape.

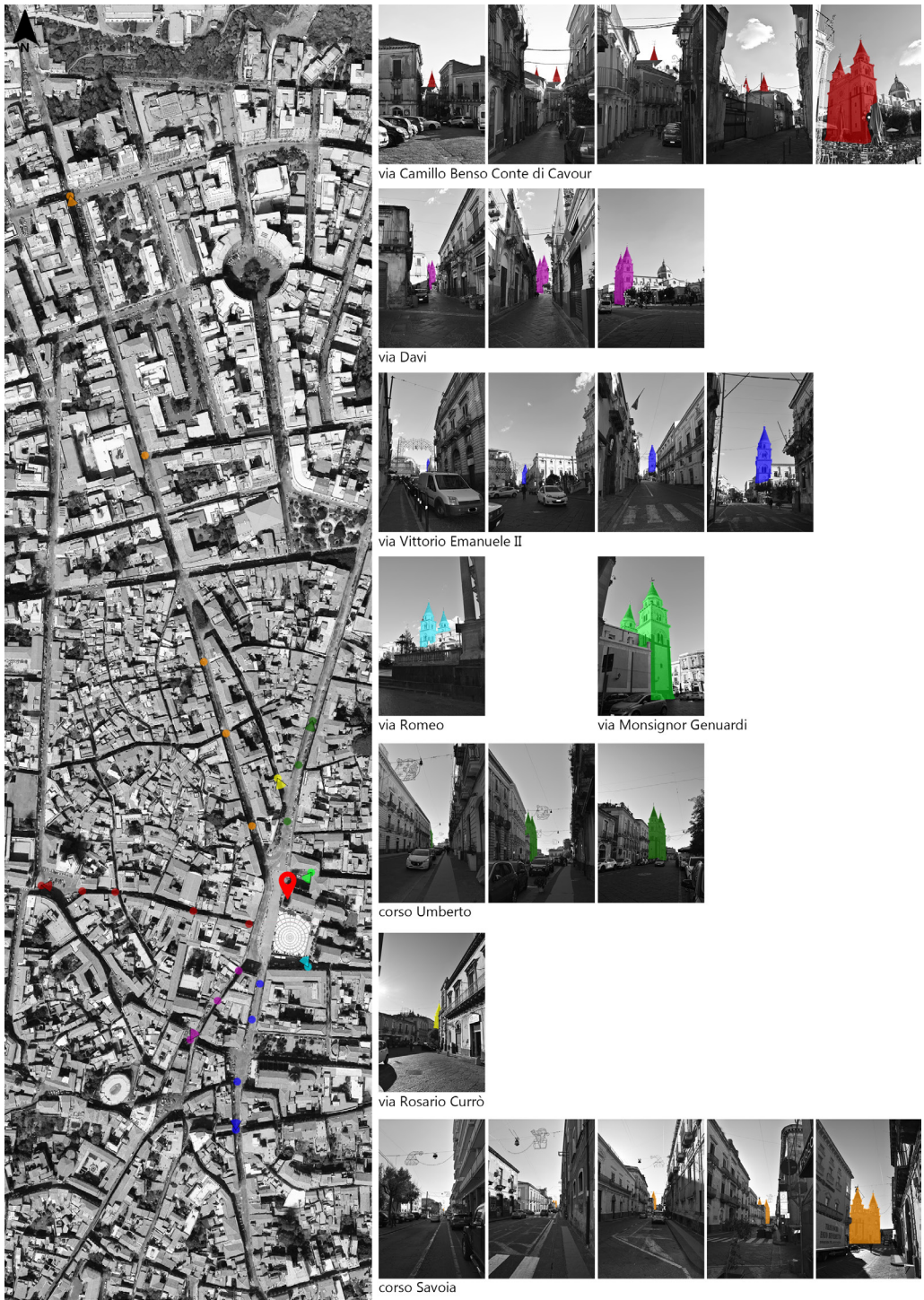


Figure 60. Visual sequences of the Cathedral of Acireale.

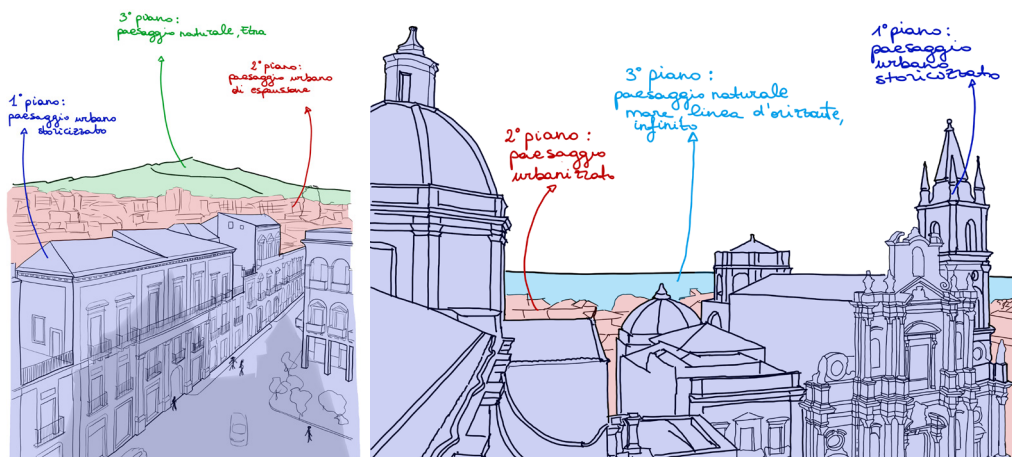


Figure 61. Perception of the urban landscape from within the towers.

The observation of the city from the towers of the Cathedral also makes it possible to interpret the urban landscape across different visual layers (Figure 61). From above, it is first possible to distinguish the historic urban landscape, characterised by the compactness of the historic centre and by the presence of the main architectural landmarks, including churches, bell towers, and domes that define the city's profile. A second layer is represented by the urban landscape of modern expansion, developed beyond the historic core and characterised by a looser urban grid and buildings of lesser monumental value. This area constitutes a transitional zone between the historic city and the surrounding territory. The third layer corresponds to the natural landscape, on the one hand dominated by the presence of Mount Etna and by the system of terracing and cultivation that characterises the foothill territory, and on the other by the horizon line defined by the sea. From this perspective, the city appears embedded within a broader landscape context in which natural and human-made elements jointly contribute to the definition of the overall image of the territory.

Glazed Wedge-Shaped Brick Spires of the Cathedral of Acireale

The towers of the Cathedral of Acireale are crowned by conical spires set on an octagonal drum and clad in polychrome glazed wedge-shaped bricks (Figure 62). These elements constitute one of the most distinctive features of the tower architecture and contribute significantly to the definition of their image within the urban landscape.

The construction technique adopted in the majolica-clad spires of Acireale corresponds to a two-leaf masonry structure built with bricks laid as headers, in which the wedge-shaped elements also perform a structural function. In their brick portion, the spires have a maximum diameter of 4.60 metres, a minimum diameter of 0.80 metres, and a height of 6.40 metres, with one hundred and eleven concentric brick courses. The uppermost part consists of a stone element that applies compression and holds the upper courses in place, onto which a metal cross with a weathervane is mounted (Figure 63).



Figure 62. Glazed wedge-shaped brick spires of the Cathedral of Acireale. Left: north tower; right: south tower.

The thickness of the spires corresponds to the length of the brick plus a thin layer of plaster on the intrados, for a total of approximately twenty-six centimetres. At present, both spires are characterised by an internal metal framework, which acts as reinforcement for the brick structure. While the southern spire retained an original wooden framework until the early twentieth century – later deteriorated and replaced by the current metal structure – the northern spire, dating to the nineteenth century, was con-



Figure 63. Upper stone elements with weathervanes and metal crosses. Cathedral of Acireale.



Figure 64. Internal metal framework. Left: north spire; right: south spire. Cathedral of Acireale.



Figure 65. South spire of the Cathedral of Acireale. Identification of bands with different decorative patterns.

structured from the outset with a metal supporting structure (Figure 64). The external metal elements supporting the cross and weathervane are connected to the internal framework.

Since each ceramic element composing the spire is monochrome, the decorative pattern is defined during the construction phase through the assembly of the elements according to geometric schemes. In the Acireale spires, the decorative pattern consists of

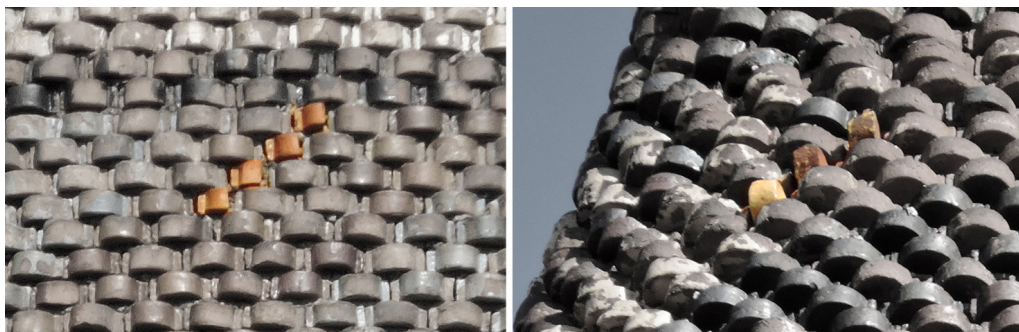


Figure 66. Half wedge-shaped bricks, laid horizontally (left) and vertically (right). Cathedral of Acireale.

a combination of horizontal bands, diagonal motifs, lozenges, and triangles (Figure 65).

At points where the number of bricks per course decreases, the vertical joints lose their staggered arrangement, creating a discontinuity in the pattern. This is concealed through the insertion of monochrome horizontal bands or by transitioning from one decorative motif to another. Furthermore, to facilitate the laying of the bricks, these were often manufactured with different tapering angles and lengths and were frequently accompanied by special pieces – such as half-bricks shaped while the clay was still fresh – which simplified installation conditions. In the case of the Acireale spires, half-bricks were used in different positions (Figure 66).

State of Conservation and Restoration Interventions

Over time, the towers of the Cathedral of Acireale and their spires have been subject to several maintenance and consolidation interventions, due both to structural issues and to the progressive deterioration of materials.

An early account of the conservation condition of the structure dates back to 1781, when the engineer Francesco Di Paola Patané was commissioned to assess the static condition of the church. In the report prepared on that occasion, he noted the severe degradation of the wooden tie-beams of the southern tower, described as deteriorated and partially compromised. The situation was further aggravated by the earthquake of 1783. A few years later, in 1791, the same engineer produced a second report in which he outlined a series of necessary interventions, including the consolidation of the tower (Bella & Grasso, 2012). At the end of the nineteenth century, new issues affecting the spire were reported, particularly the presence of cracks³. In 1903, the engineer Francesco Valenti was commissioned to assess the condition of the urgent works carried out on the bell tower. The report produced on that occasion documents the presence of significant cracking in the structure and the deterioration of the internal wooden framework of the spire, already compromised by ageing. The document also includes a survey of the crack pattern of the tower, in which it is possible to identify a fracture in a position sim-

³ Archivio Soprintendenza ai beni Culturali e Ambientali di Catania. CT 4-1, Acireale Cattedrale. *Floristella*, lettera del 9/02/1895 al Direttore dell'Ufficio Regionale per la Conservazione dei Monumenti della Sicilia a Palermo, Arch. G. Patricolo, 4-1 23.

ilar to that still visible today in the spire⁴. The following year, the static problems of the tower were still unresolved, to the extent that the Vicar General La Spina sent a further request for their repair⁵. Two further significant episodes occurred in 1971 and 1972, when some polychrome bricks detached from the spire of the northern tower due to strong wind gusts that set the metal rod of the weathervane into vibration. Following the first event, the spire was temporarily encased in a provisional structure made of metal tubes and joints⁶. In the following years, more systematic interventions were planned, culminating in the restoration and consolidation works carried out on both towers between 1983 and 1985.

Alongside the main events documented in historical sources, direct observation of the spires today reveals a range of deterioration phenomena related both to the nature of the materials and to the exposure conditions of the ceramic elements.

The brick-laying system favours the infiltration of water within the outer surface and the accumulation of soil transported by the wind in projecting areas. These conditions promote the growth of invasive vegetation, which acts both mechanically and chemically, progressively disaggregating mortar joints and bricks (Figure 67g).

Further critical elements are represented by the metal components located at the top and within the spires – such as crosses, weather vanes, maintenance ladders, and tie-rod heads – which, in addition to altering the chromatic appearance of the surfaces due to runoff staining, may cause cracking phenomena in the ceramic elements and along the mortar joints (Figures 67a-67b).

Moreover, the combined action of water and wind promotes both chemical and physical deterioration of the ceramic surfaces. The transport of solid particles and corrosive substances leads to dissolution and abrasion processes affecting both the glaze (Figure 67e) and the underlying ceramic body (Figure 67d). At the same time, wind and water carry dust, salts, and pollutants that tend to accumulate and stratify on the brick surfaces.

In areas where the mortar is more degraded, cracks and fractures are also present, developing predominantly along the joints between the bricks and defining a crack pattern affecting various portions of the spire surface (Figure 67c). In some cases, these lesions have been subject to repair interventions carried out through joint repointing using cement-based mortars, often applied in an invasive manner and with materials not always compatible with the original ones (Figure 67f). Although intended to seal cracks and restore surface continuity, such interventions alter the readability of the masonry surface and may, over time, contribute to the development of further deterioration phenomena.

4 Archivio Soprintendenza ai Beni Culturali ed Ambientali di Catania. CT 4-1, Acireale Cattedrale. *Valenti Francesco, 1903, Cattedrale di Acireale. Ispezione al campanile antico, relazione presentata all'Ufficio Regionale per la Conservazione dei Monumenti della Sicilia del Ministero della Istruzione Pubblica stesa dal Prof. Valenti, 4-1 25.*

5 Archivio Soprintendenza ai Beni Culturali ed Ambientali di Catania. CT 4-1, Acireale Cattedrale. *La Spina G. Vicario Generale, lettera del 23/11/1904 al Barone di Floristella, 4-1 41.*

6 Archivio Soprintendenza ai Beni Culturali ed Ambientali di Catania. Carpetta CT 4-1 A, Cattedrale Maria SS. Annunziata, Acireale. *Documenti relativi alla caduta di elementi murari dalla cuspide nord, 2-6-8-A.*

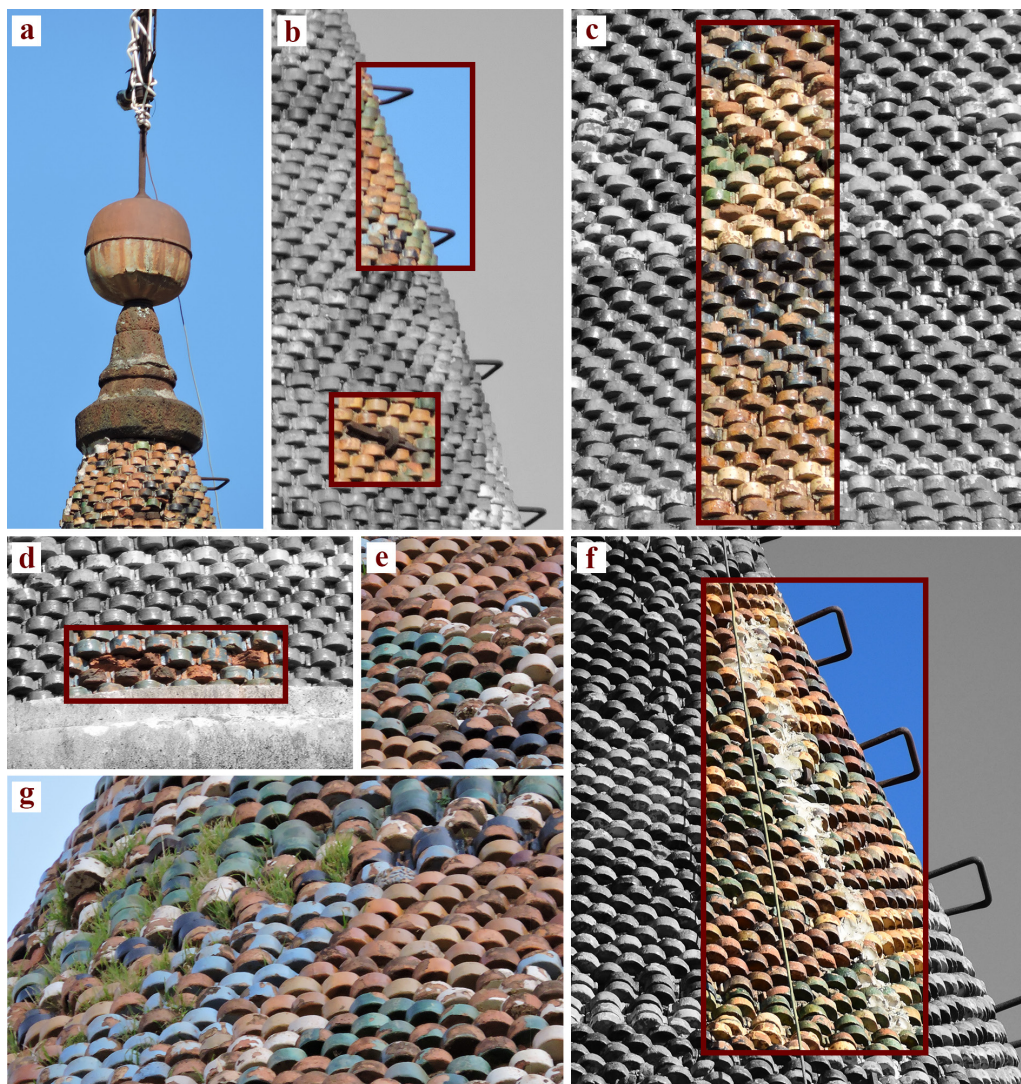


Figure 67. Visible deterioration phenomena. Spires of the Cathedral of Acireale.

Integrated Survey of the Towers of the Cathedral of Acireale

The documentation of the towers of the Cathedral of Acireale and their spires was carried out through an integrated survey campaign aimed at producing high-resolution three-dimensional models suitable for the geometric, architectural, and material analysis of the structures. The morphological complexity of the towers and their spires, combined with their considerable height, required the combined use of different acquisition techniques to ensure complete surface coverage and an accurate representation of the geometries.

In particular, the laser scanning instrumentation employed consisted of three laser scanners, two terrestrial and one mobile based on SLAM technology (Figure 68). The

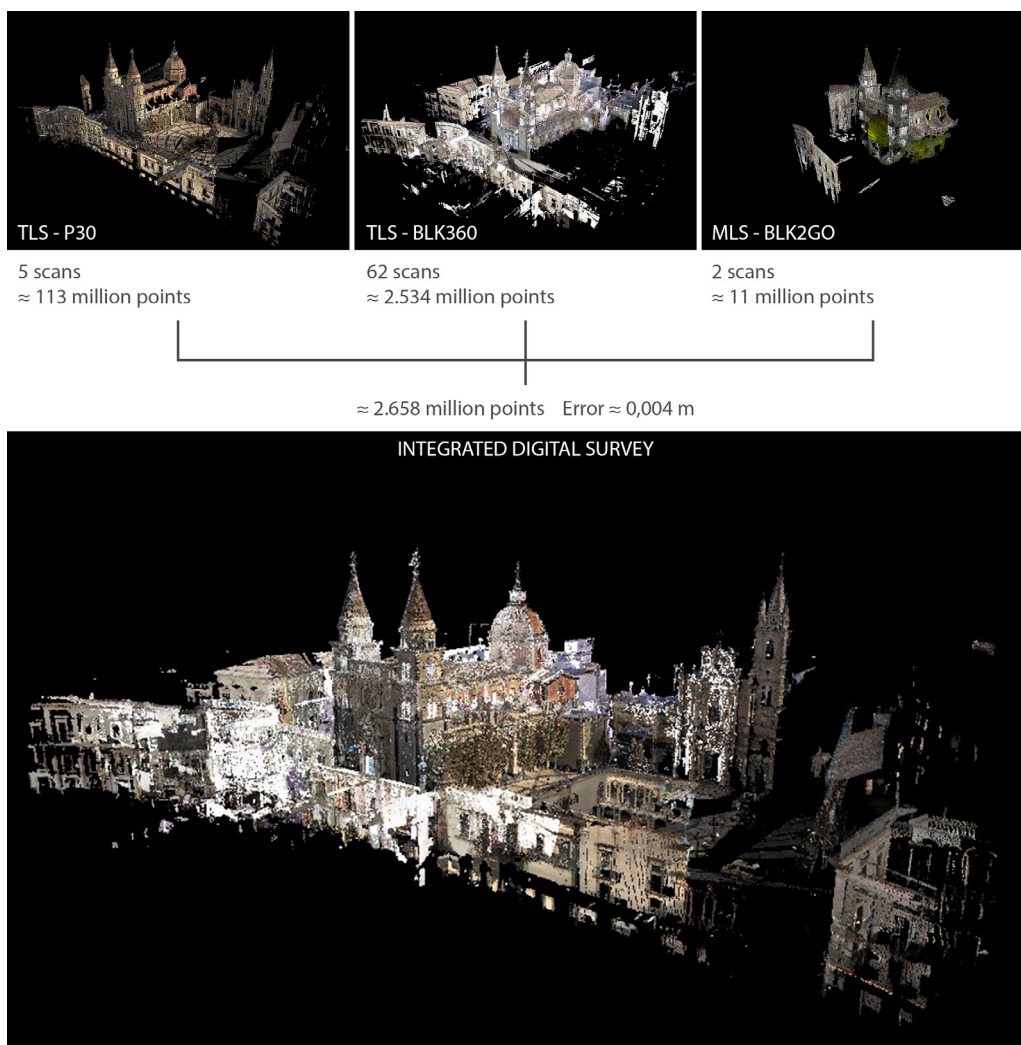


Figure 68. Point clouds obtained from surveys using three laser scanners: P30, BLK360, BLK2GO. Cathedral of Acireale.

imaging laser scanner BLK360 was used for surveying the interior of the cathedral and certain areas within the bell towers, which were necessary for the alignment of the point clouds obtained from the other laser scanners. The time-of-flight laser scanner P30 was used for surveying the exterior of the cathedral. The mobile laser scanner BLK2GO was used for surveying the interiors of the bell towers (Figure 69). The acquired data were then integrated into a single numerical model consisting of approximately 2.6 billion points, obtained from sixty-seven fixed stations and two mobile scans for the survey of the entire church (Figure 70). Of these, with specific reference to the two towers and the areas connecting them, the relevant scans include twenty-one acquired with the BLK360, five with the P30, and two with the BLK2GO.

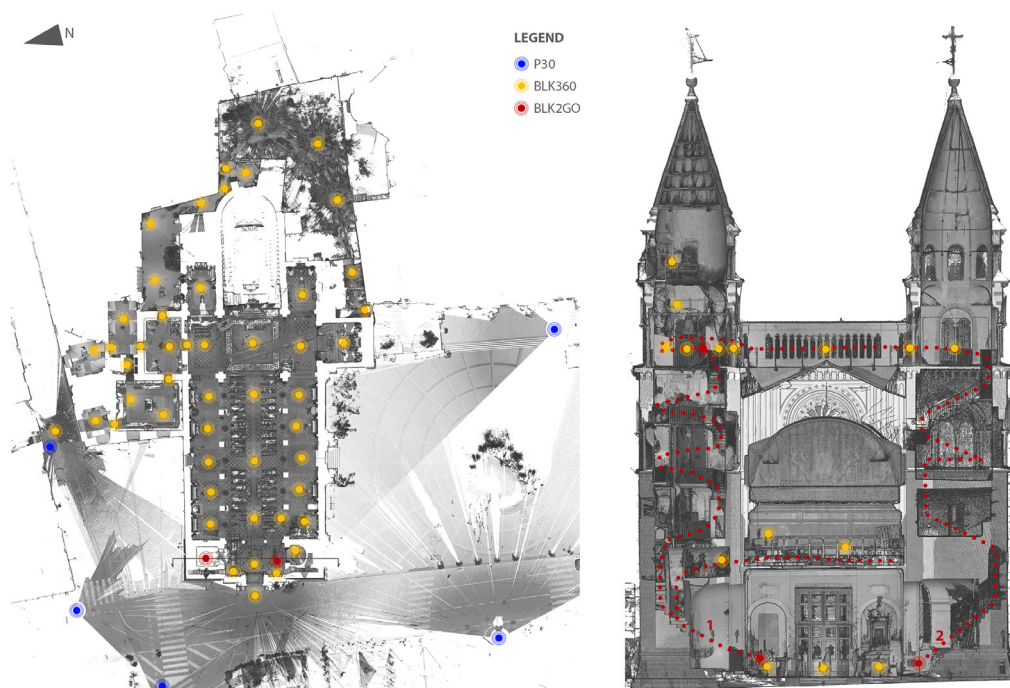


Figure 69. Position of scan stations (in blue, P30; in yellow, BLK360) and trajectory of the mobile laser scanner BLK2GO (in red). Cathedral of Acireale.

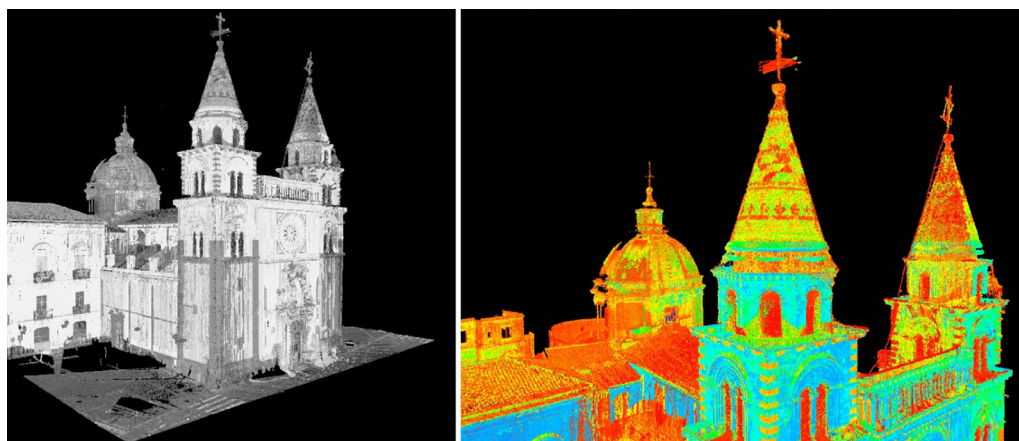


Figure 70. Point cloud of the Cathedral of Acireale.

The SfM survey was carried out using a digital camera mounted on an unmanned aerial vehicle (DJI Mini 2 with integrated camera). For the acquisition of the entire main façade and all elevations of the bell towers, 257 photographs were taken (Figure 71) and subsequently processed using the professional software Agisoft Metashape. The resulting three-dimensional point cloud consists of approximately 30 million points, while the mesh comprises approximately 5 million triangles (Figures 72-73).

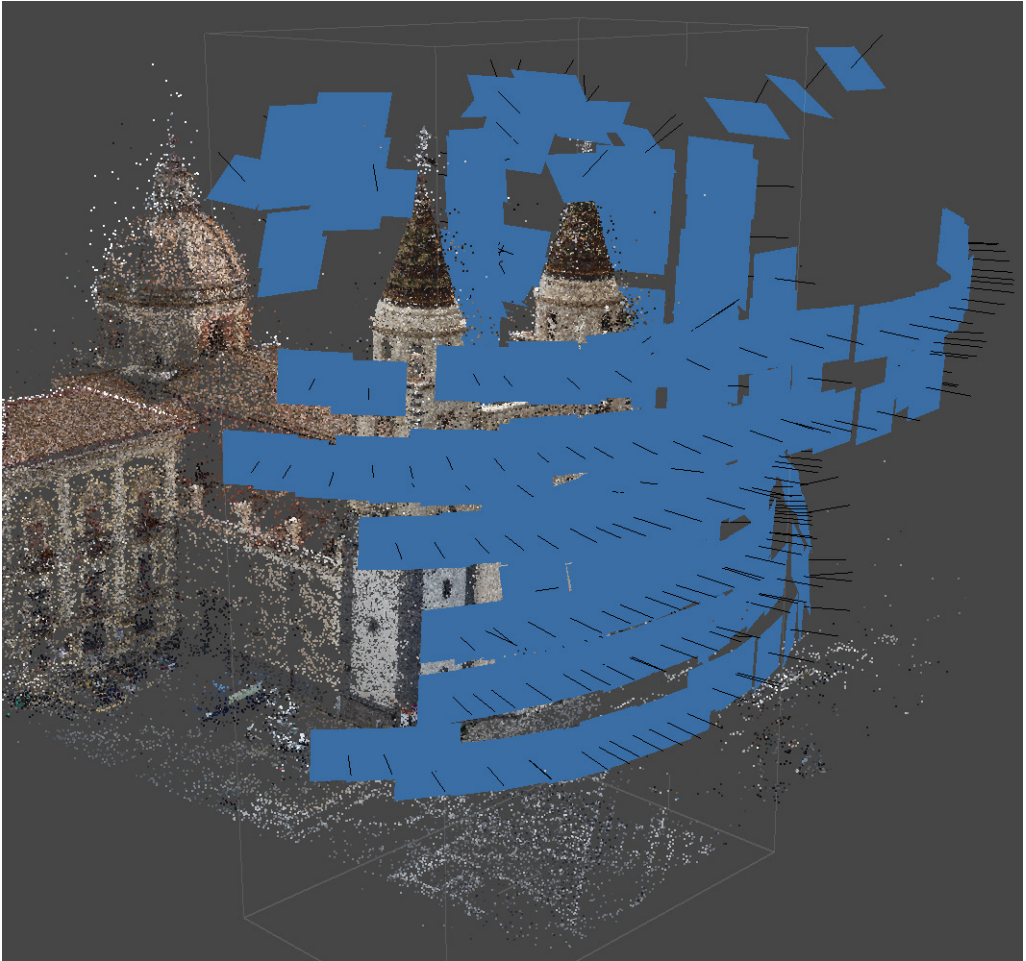


Figure 71. Camera positions during UAV-based survey, Cathedral of Acireale.



Figure 72. Three-dimensional model derived from UAV photogrammetry. Processing stages in Agisoft Metashape. From left: sparse point cloud, dense point cloud, textured mesh. Cathedral of Acireale.



Figure 73. Detail of the photogrammetric point cloud of the south spire of the Cathedral of Acireale.

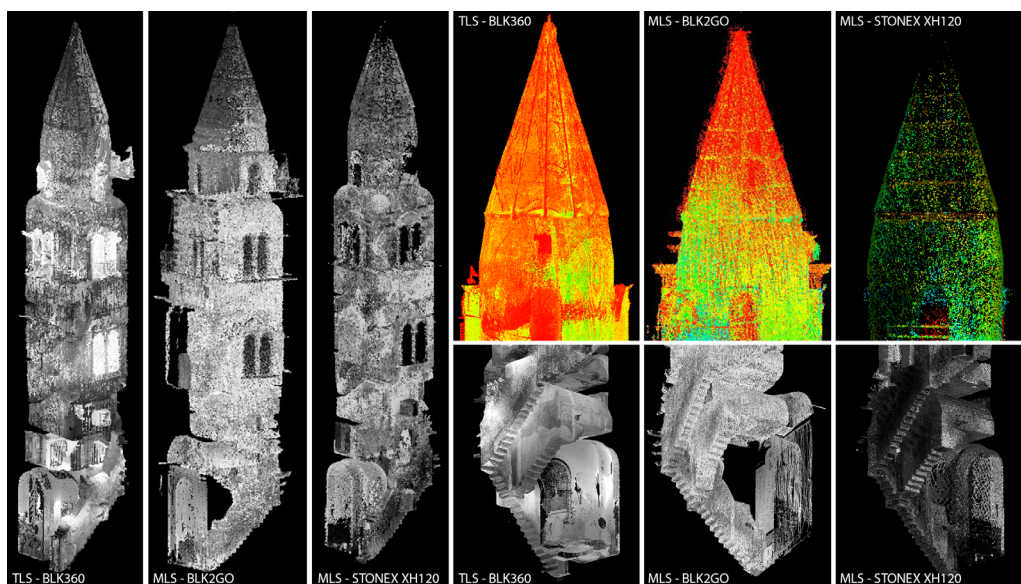


Figure 74. Comparative analysis of the point clouds obtained using the three different laser scanners. Cathedral of Acireale.

The interior of the south bell tower was surveyed using three different instruments in order to carry out a comparison and identify the most suitable tool for similar case studies.

For the first survey, the terrestrial laser scanner Leica BLK360 was used, with which twenty-seven scans were carried out inside the bell tower. The resulting survey is highly detailed but extremely time-consuming. Given the complexity of the environment, a large number of scans was required to cover all parts of the tower and to obtain a point cloud as homogeneous as possible in terms of point distribution.

A second survey of the bell tower was then carried out using two mobile laser scanners. The first instrument was a SLAM XH120 produced by STONEX, with which a single scan was performed starting from the central nave, ascending the bell tower and returning to the starting point in order to create a closed loop, thus reducing the likelihood of trajectory drift. The second instrument was a Leica BLK2GO, with which two scans were performed.

The accuracy and reliability of the models obtained from the three different laser scanners were evaluated through a comparative analysis of the respective point clouds in terms of number of points, point density, supported representation scale, noise level, acquisition and processing times, and point cloud size (Figure 74, Table 13). For mobile laser scanners, acquisition times derive from the sum of the initialisation phase and the acquisition trajectory, whereas for terrestrial laser scanners they derive from the sum of positioning and acquisition phases for each individual scan. Processing times include the registration of the different scans into a single reference system and the subsequent phases of cleaning and decimation.

Table 13. Comparison of the point clouds obtained using the three different laser scanners, including acquisition and processing times. South tower of the Cathedral of Acireale.

	TLS LEICA BLK360	MLS LEICA BLK2GO	MLS STONEX SLAM XH120
Points number	≈1,4 billion	≈7 million	≈5 million
Points density	high	low	low
Restitution scale	1:20	1:50	1:100
Noise level	low	high	high
Acquisition time	6 h	11 min	15 min
Processing time	8 h	45 min	30 min
Weight (.las)	≈35 GB	4 GB	≈0,7 GB

Graphical Representation of Survey Outputs

The resulting numerical models made it possible to document both the geometry and the material characteristics of the towers and their spires with a high level of detail, allowing a dynamic use of the investigated architecture in which the observer can analyse the construction in depth. Starting from the point clouds obtained through the integration of the different acquisition techniques, it was possible to develop a series of graphical outputs useful for the geometric and architectural documentation of the artefact.

The outputs produced include plans, sections, and elevations of the towers, which allow the planimetric and altimetric configuration of the structures to be described with precision and highlight the dimensional relationships between the different structural levels. In particular, the vertical sections show the relationship between the tower body, the octagonal drum, and the conical spire, highlighting the continuity between the different parts of the construction system (Figures 75-76).

The three-dimensional model derived from the point cloud also constitutes a fundamental tool for the morphological and material analysis of the spires. Based on the survey data, two different levels of modelling were developed: a three-dimensional model of the entire tower, represented with a level of detail compatible with a 1:100 scale (Figure 77), and a second, more detailed model of the spire alone (Figure 78). In the latter case, the modelling made it possible to represent the arrangement of the wedge-shaped brick courses and the qualitative configuration of the ceramic elements contributing to the formation of the decorative patterns.

The integration of two-dimensional outputs and the three-dimensional model therefore allowed for the creation of a comprehensive documentation of the towers and their spires, useful both for understanding the construction characteristics of the artefact and as a knowledge base for potential further analyses and conservation interventions. The produced outputs are also made available to users through the database developed within the research, allowing the integration of graphical documentation with descriptive and territorial data.

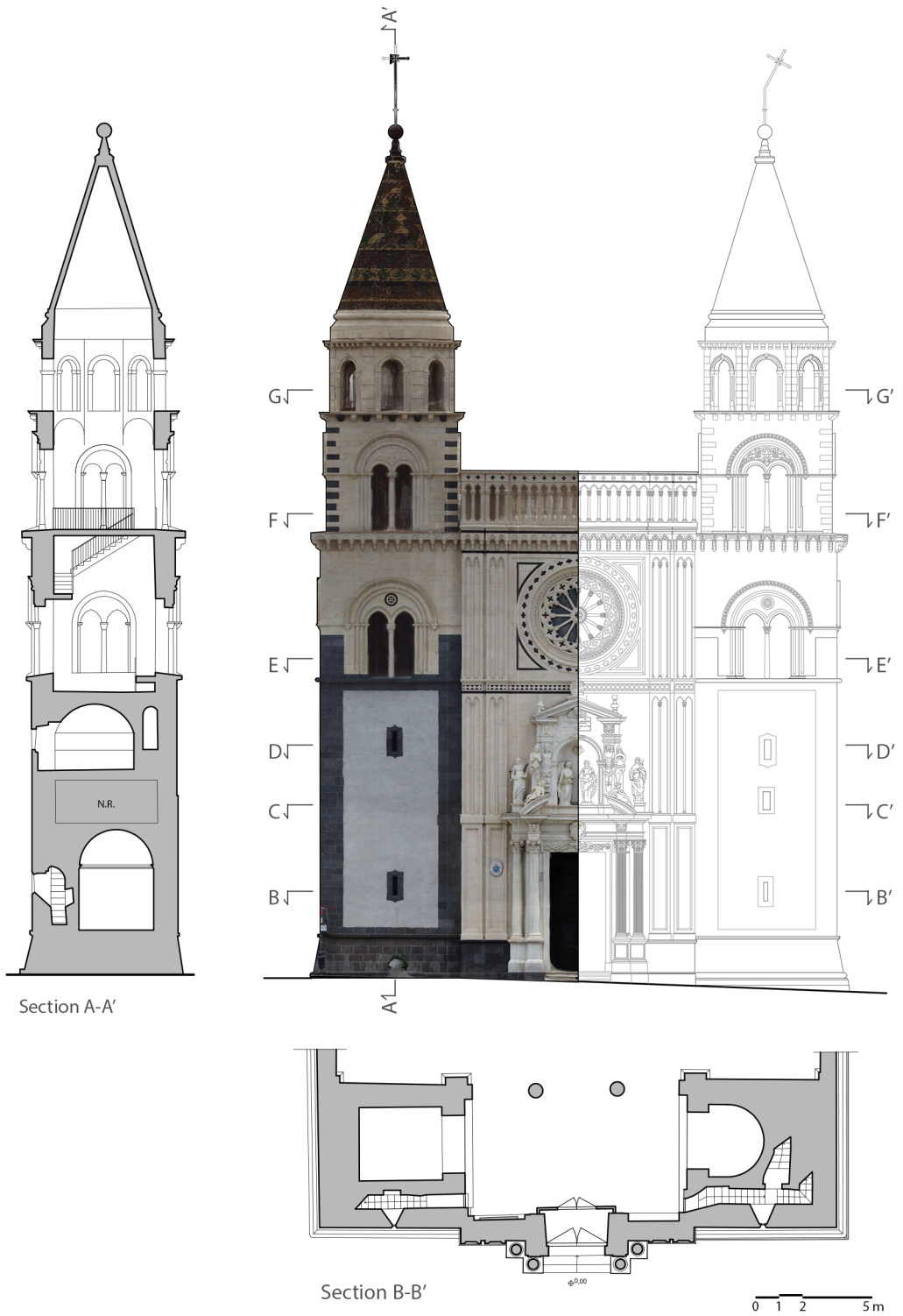
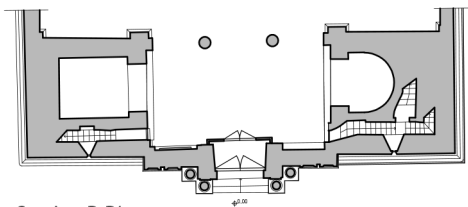
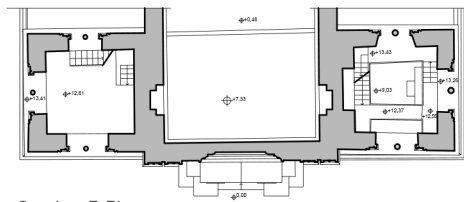


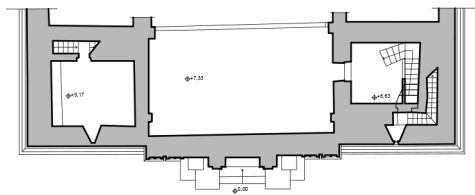
Figure 75. Two-dimensional graphical outputs of the towers of the Cathedral of Acireale.



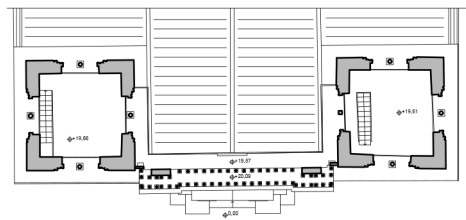
Section B-B'



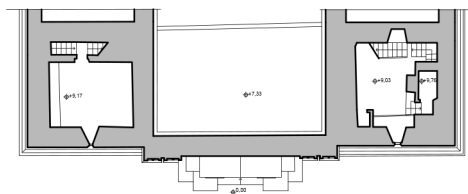
Section E-E'



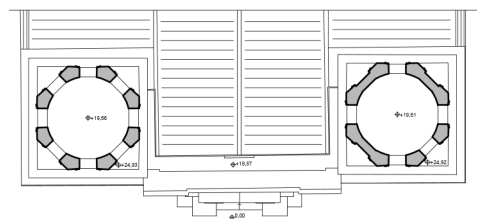
Section C-C'



Section F-F'



Section D-D'



Section G-G'

0 1 2 5m

Figure 76. Floor plans at different levels of the towers of the Cathedral of Acireale.

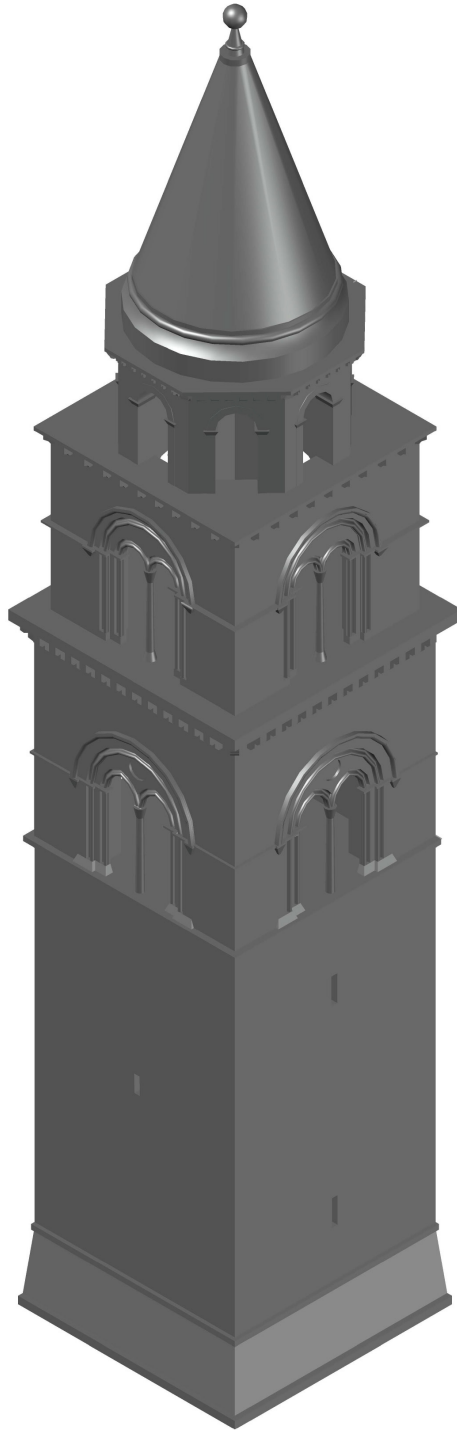


Figure 77. Three-dimensional model of the north tower of the Cathedral of Acireale with a level of detail comparable to a 1:100 scale.



Figure 78. Three-dimensional model showing the decorative pattern of the spires of the Cathedral of Acireale.



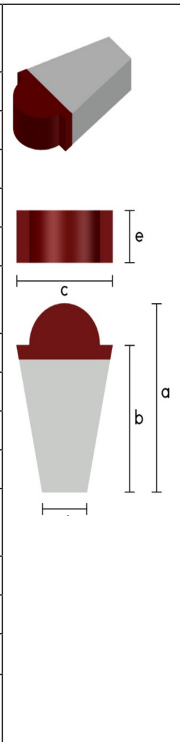
Figure 79. Sample of analysed bricks.

Morphological Analysis of Glazed Wedge-Shaped Bricks

In order to investigate in greater detail the geometric and constructive characteristics of the wedge-shaped bricks used in the spires of the Cathedral of Acireale, a morphological analysis was carried out based on both direct survey and high-resolution digital

Table 14. Sample of analysed bricks.

Sample	a [cm]	b [cm]	c [cm]	d [cm]	e [cm]	Mass [kg]	Glaze colour	Notes
Aci 1	21.0	17.5	10.5	5.5	4.3	1.123	blue	
Aci 2	21.5	18.0	10.3	5.5	4.0	1.101	blue	
Aci 3	21.0	17.5	10.5	5.7	4.3	1.152	yellow	
Aci 4	21.0	17.5	11.0	5.5	4.0	1.099	blue	
Aci 5	21.0	17.7	11.0	5.7	4.0	1.082	blue	
Aci 6	21.0	17.5	10.2	5.5	4.0	1.092	red-brown	
Aci 7	21.0	17.8	10.2	5.2	4.0	1.093	brown	
Aci 8	21.7	17.8	10.6	5.3	3.8	1.051	yellow	
Aci 9	20.8	17.2	10.4	5.3	4.2	1.105	green	
Aci 10	21.8	18.0	10.6	6.7	4.0	1.358	white	
Aci 11	19.7	15.0	10.4	-	3.8	0.996	white	broken; finger marks
Aci 12	21.7	17.8	10.4	6.5	4.0	1.270	-	unglazed
Aci 13	21.3	17.4	9.2	6.5	3.8	1.970	yellow	
Aci 14	22.0	17.4	10.4	7.7	3.9	1.380	green	
Aci 15	20.5	17.0	9.0	5.3	4.0	1.110	brown	firing deformation



acquisition techniques. The study focused on a sample of fifteen ceramic elements belonging to the spires, allowing their main dimensional and geometric characteristics to be documented (Figure 79).

Visual inspection revealed that these are relatively coarse ceramic products. The clay body appears to be rough, with inclusions, firing defects, and deformations. The average values of dimensions and weight are summarised in Table 14. The bricks of the Acireale spires are characterised by a white slip coating covered by a semi-transparent coloured glaze. Six colours are used, namely white, yellow, red-brown, brown, green, and light blue, obtained using different oxides during the glaze preparation phase (Table 15).

The survey of the brick was carried out using a structured-light laser scanner (SCANTECH iReal 2E). The resulting high-resolution three-dimensional model is represented by a triangular mesh composed of approximately 68 thousand vertices and 118 thousand triangular faces, allowing the geometry of the ceramic element to be documented with a high level of detail (Figure 80).

Table 15. Qualitative estimation of the percentage of bricks in the spire according to glaze colour.

Brick Colour	Oxide Used	No. of Bricks (estimated)	Percentage of Bricks
White	-	1450	17.7%
Yellow	Iron	1100	13.4%
Red-Brown	Manganese	900	11.0%
Brown	Manganese	850	10.4%
Green	Copper	1400	17.1%
Blue	Cobalt	2500	30.4%

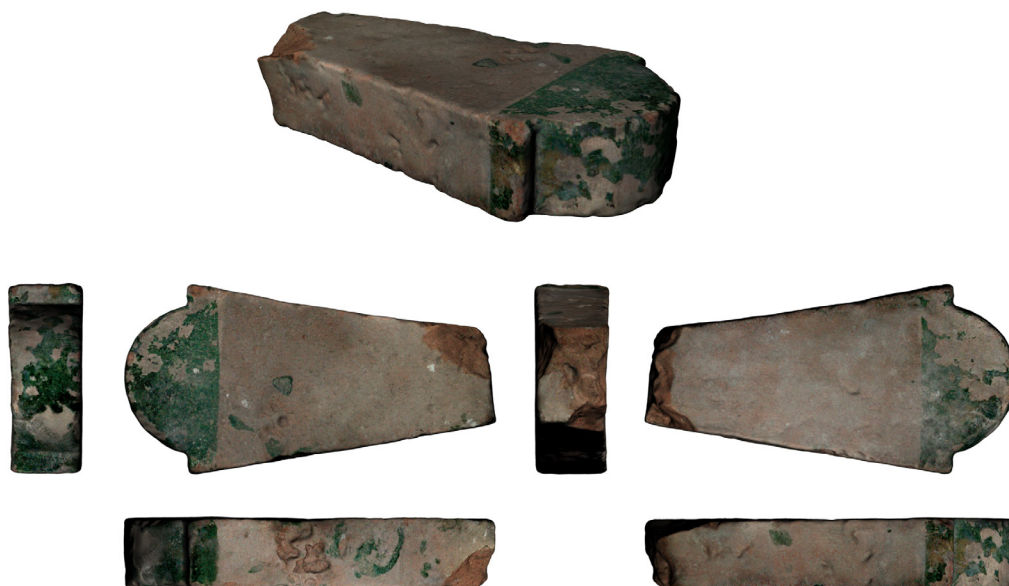


Figure 80. Mesh model of the surveyed brick from the spires of the Cathedral.

8.3.2 - The Bell Tower of the Basilica of Santa Caterina Alessandrina in Pedara

Historical and Architectural Overview

The Basilica of Santa Caterina Alessandrina is located in the historic centre of Pedara, in a dominant position overlooking the main urban square (Piazza Don Diego), establishing itself as both a spatial and symbolic landmark within the Etnean settlement fabric (Figure 81). The current urban and architectural configuration of the complex is the result of a long evolutionary process, strongly influenced by natural events that have affected the area, particularly lava flows and earthquakes which, between the fifteenth and seventeenth centuries, led to significant transformations of the settlement.

Historical sources indicate that the original settlement underwent substantial changes following the eruptions of 1408 and 1444, which caused a progressive relocation of the inhabited centre towards safer areas. Within this context, the construction history of the mother church is to be understood. Originally dedicated to the Annunciation, it was subsequently rebuilt and enlarged during the sixteenth century, culminating in the reconstruction of the building in 1547. Following the severe damage caused by the earthquake of 1693, which affected the whole of eastern Sicily, the church was rebuilt once again, assuming its present configuration, attributable to the late-Baroque period (De Luca, 2005; Pappalardo, 2009a, 2009b).

From an architectural perspective, the basilica presents a monumental layout, emphasised by its elevated position in relation to the urban plane and by the broad access

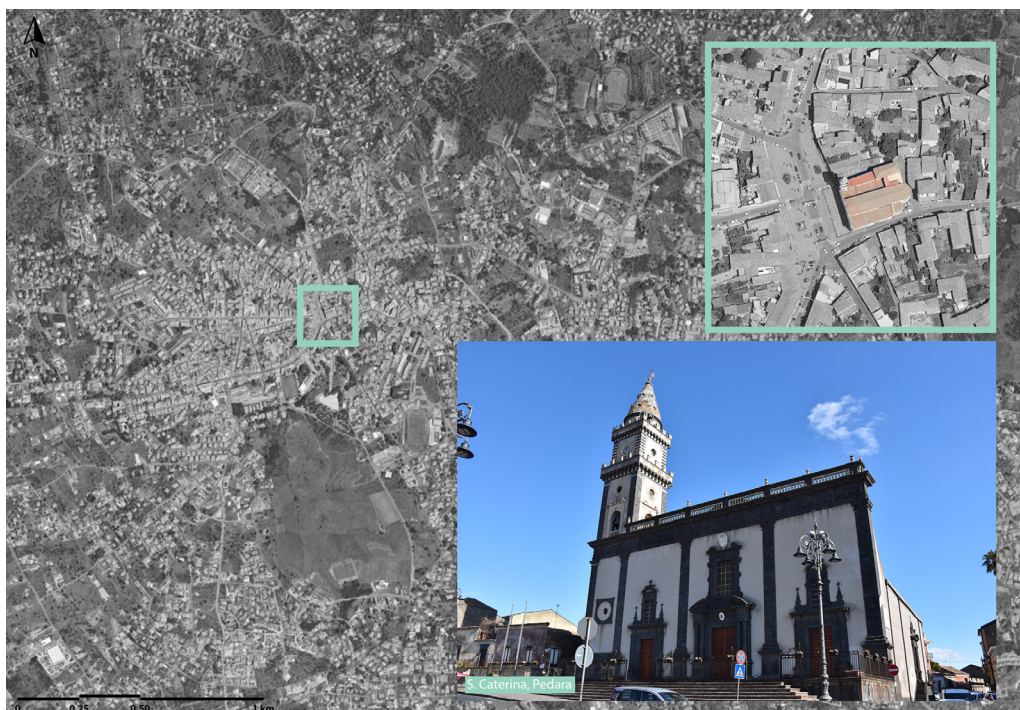


Figure 81. Location of the Basilica of Santa Caterina in Pedara.



Figure 82. Historical photographs of the Basilica of Santa Caterina. Left, an undated postcard; right, a photograph from the 1930s.

staircase, which reinforces its role as a visual landmark within the surrounding context (Figure 82). The main façade, articulated according to an ordered composition and defined by stone elements in lava stone, displays a refined chromatic interplay between plastered surfaces and decorative elements, typical of Etnean architecture. The façade clearly reflects the internal organisation of the building, expressed through the vertical articulation of its architectural elements. The basilica plan develops according to a longitudinal tripartition consisting of three naves divided into six bays. The central nave, of larger dimensions, is covered by a barrel vault with lunettes, while the side aisles are covered by cross vaults. The spatial system culminates in the apse area, where the main nave terminates in the high altar, flanked laterally by smaller chapels corresponding to the side aisles, resulting in a planimetric and volumetric arrangement consistent with the composition of the façade.

The bell tower, positioned laterally with respect to the main façade, is configured as an autonomous architectural volume, clearly distinguishable from the body of the church both in plan, with a quadrangular layout, and in elevation, where it appears as an independent block rising above the roofline of the building. The tower develops vertically through several superimposed levels. In the lower part, the shaft is characterised by a stepped base, while in the upper part the belfry is located, surmounted by an additional level housing the clock. Above this structure, a cylindrical drum is set, acting as a transitional element between the prismatic geometry of the tower and the upper covering, consisting of a conical spire made of polychrome ceramic wedge-shaped bricks. These upper levels are also characterised by the presence of walkways bordered by crenellated parapets.

The Glazed Wedge-Shaped Brick Spire of the Basilica of Santa Caterina

The upper covering of the bell tower consists of a conical spire set on a cylindrical drum, which provides the transition between the prismatic volume of the tower and the terminal element. The spire has a height of approximately 7.00 m and a base diameter



Figure 83. Spire of the Basilica of Santa Caterina.

of approximately 5.20 m, configuring itself as an element of significant volumetric presence within the profile of the bell tower.

The external surface of the cone is clad in ceramic wedge-shaped bricks arranged in 125 concentric courses. The cladding displays a rich chromatic articulation, with the use of green, light blue, yellow, white, and brown tones, organised according to a decorative scheme combining horizontal bands, diagonal bands, and lozenge patterns (Figure 83).

Although it was not possible to directly verify the nature of the surface treatment of the bricks, the visual characteristics suggest the use of glazed or vitreous elements, in line with the tradition of polychrome ceramic coverings widespread in the Etnean area.

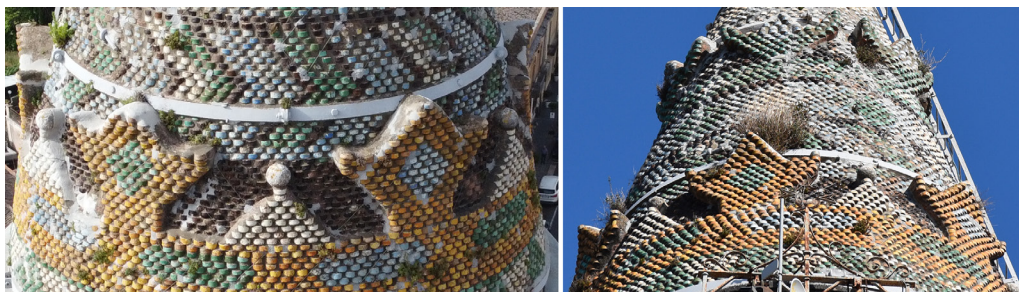


Figure 84. Details of the spire of Santa Caterina.

The surface of the spire also presents projecting brick elements, which confer a different degree of plasticity compared to the other analysed spires (Figure 84).

Access conditions did not allow for a direct survey of the interior of the spire, due to the inadequate safety conditions of the uppermost level of the bell tower. However, based on archival photographic documentation, it is possible to identify the presence of an internal structure consisting of a metal cage articulated through circular elements arranged along the perimeter and connected by tie rods, which perform a containment and stabilising function (Figure 85). Externally, this system is evidenced by the anchor plates of the tie rods and by metal rings adhering to the surface and connected to the internal structure. Additional devices are also present, including a service ladder for maintenance and a network of steel cables, almost imperceptible to the eye, which wraps around the surface of the spire (Figure 84). The latter, most likely introduced in later phases, responds to consolidation and safety requirements, although partially altering the original formal reading.

From a conservation perspective, the visual analysis of the external envelope highlights several critical issues, including the widespread presence of invasive vegetation, particularly concentrated in correspondence with projecting elements that favour the accumulation of soil, phenomena of glaze erosion and loss, and maintenance interventions carried out with incompatible materials such as cement-based mortars (Figure 86). These interventions are documented in a restoration carried out in 1977, which included cleaning of the joints, removal of vegetation, replacement of damaged ceramic



Figure 85. Internal metal structure of the spire of Santa Caterina. Source: Archivio della Soprintendenza per i Beni Culturali e Ambientali di Catania, CT 34-1.

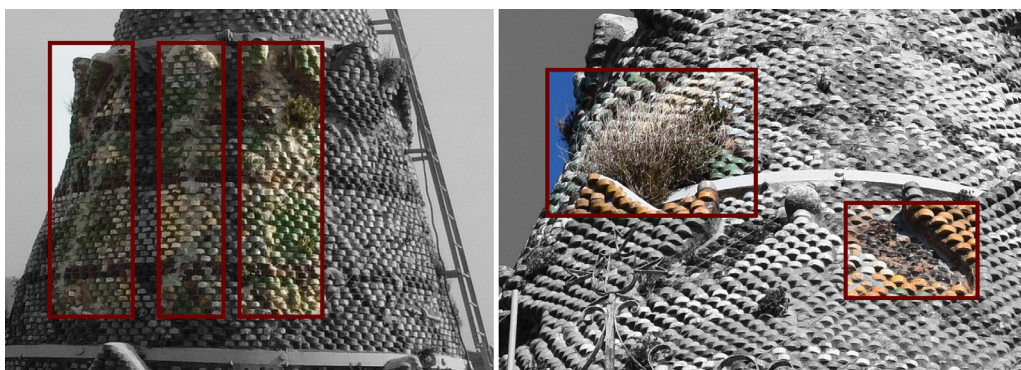


Figure 86. Visible deterioration phenomena in the spire of Santa Caterina. Left, interventions with incompatible materials; right, invasive vegetation and glaze erosion.

elements, estimated at up to 10%, and subsequent repointing of the surfaces using cement-based mortar⁷.

Overall, the spire of the bell tower of the Basilica of Santa Caterina represents a significant example of a conical covering clad in polychrome bricks, in which the decorative component is integrated with complex technical and structural solutions, configuring it as a case of particular interest for the analysis of traditional construction techniques and subsequent interventions of transformation and restoration. This configuration assumes a character of particular rarity, as, based on the current state of knowledge, it does not find correspondence in analogous technical and decorative solutions among the other spires documented within the present research.

Integrated Survey of the Basilica of Santa Caterina and Its Tower

The survey of the Basilica of Santa Caterina Alessandrina in Pedara was aimed at the geometric and material documentation of the entire architectural complex, with particular attention to the bell tower and the configuration of the spire, in order to support the subsequent phases of analysis and representation.

The acquisition campaign was carried out through the integration of instrumental and photogrammetric survey techniques, following a methodological approach already tested in the case study of the Cathedral of Acireale and adapted to the specific conditions of the building. The survey operations were organised considering the complexity of the architectural organism, the vertical development of the bell tower, and the limited accessibility of the uppermost parts.

The terrestrial laser scanning survey involved the combined use of different instruments to optimise data acquisition according to the various spatial conditions. In particular, the Leica P30 instrument was used for the external areas, while a Leica BLK360 device was employed for the internal spaces and for some connecting areas with the

⁷ Archivio Soprintendenza ai Beni Culturali e Ambientali di Catania. CT 34-1, *Perizia di spesa n°8 per i lavori di restauro e consolidamento, 08/02/1977 and Progetto di restauro e consolidamento della chiesa di S. Caterina (Duomo) – Analisi dei prezzi relativa alla perizia n°8, 08/02/1977.*

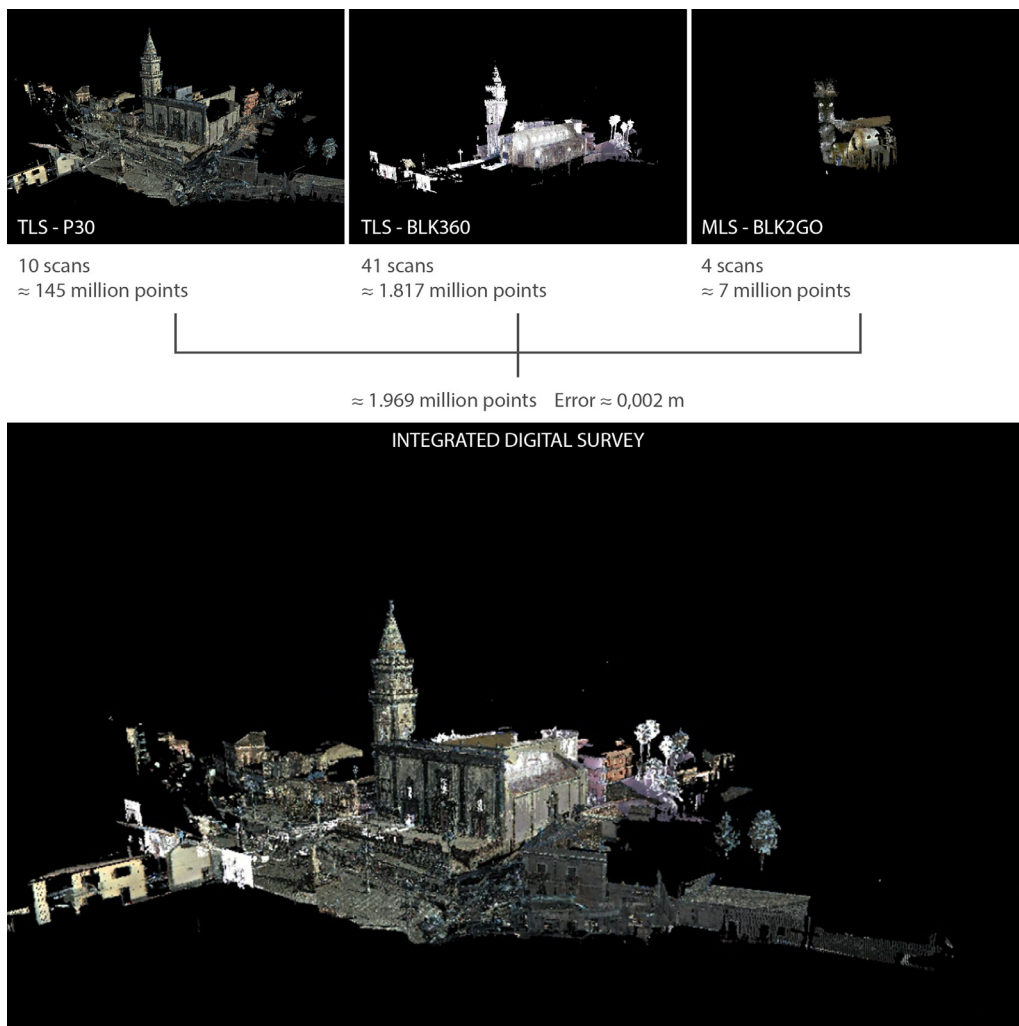


Figure 87. Point clouds obtained from surveys of Santa Caterina using three laser scanners: P30, BLK360, BLK2GO.

exterior. For the survey of the bell tower, a mobile SLAM system, Leica BLK2GO, was also used, allowing more efficient acquisition within vertical spaces and internal paths. In total, 55 scans were carried out, including 4 mobile scans, for a total of approximately 2 billion acquired points (Figures 87-88-89).

In parallel, a photogrammetric campaign specifically dedicated to the survey of the tower, and in particular of the spire, was carried out using a DJI Mini 2 drone with integrated camera. A total of 193 images were acquired (Figure 90) and subsequently processed using Agisoft Metashape software, in order to generate a dense point cloud consisting of approximately 3.4 million points and a three-dimensional mesh composed of approximately 59 thousand triangles (Figure 91). This methodology enabled high-resolution documentation of the external surfaces and proved particularly effective for the analysis of the ceramic cladding and decorative patterns (Figure 92).

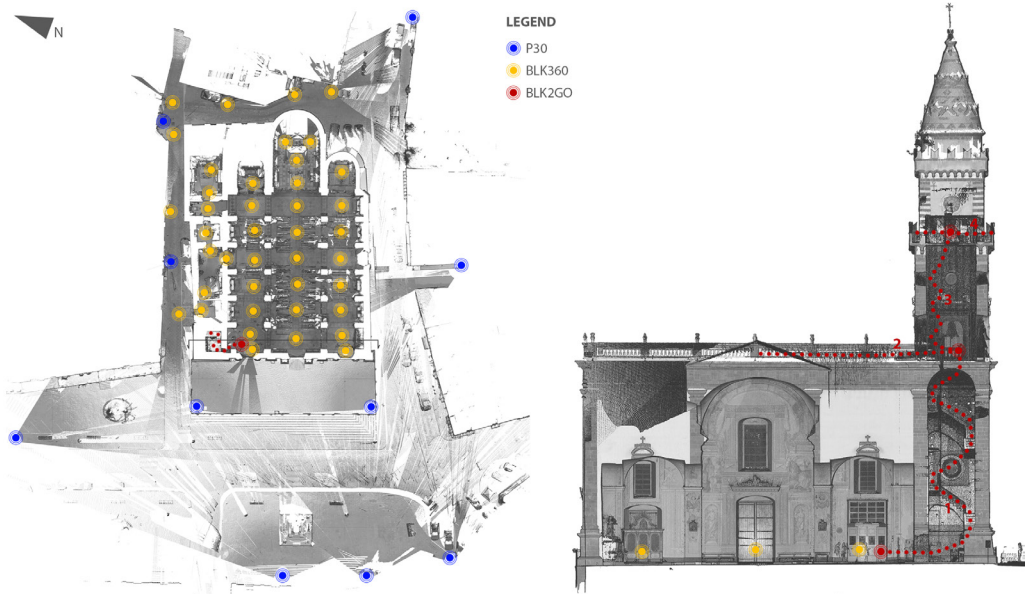


Figure 88. Position of scan stations (in blue, P30; in yellow, BLK360) and trajectory of the mobile laser scanner BLK2GO (in red) in Santa Caterina.

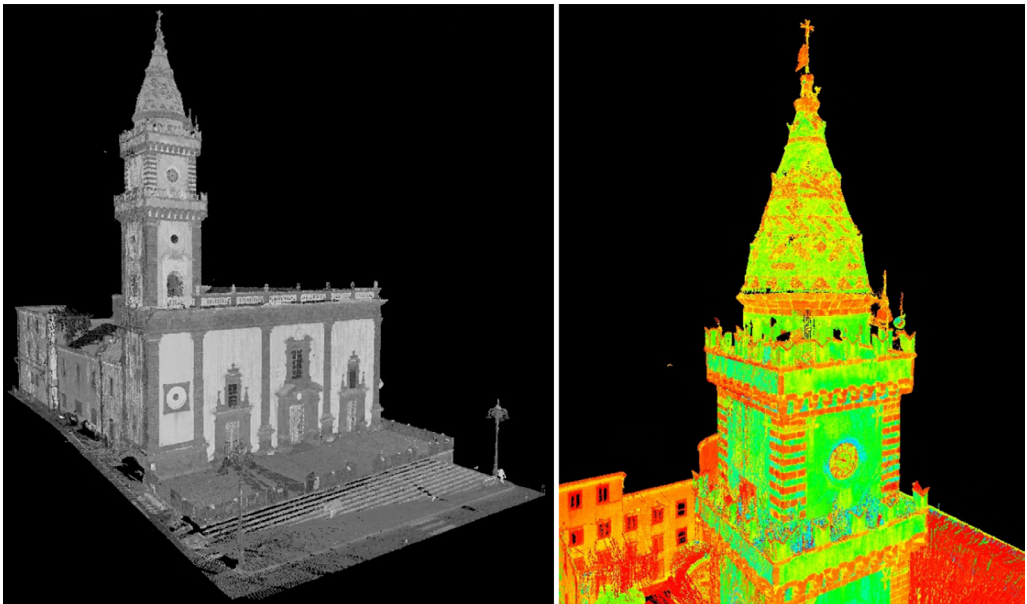


Figure 89. Point cloud of the Basilica of Santa Caterina.

The data processing operations included the registration and alignment of laser scans, the generation of the overall point cloud, and its subsequent integration with the photogrammetric data. Based on these datasets, high-resolution three-dimensional models and orthophotos were produced, which were used as the basis for graphical representation and for morphological and material analyses.

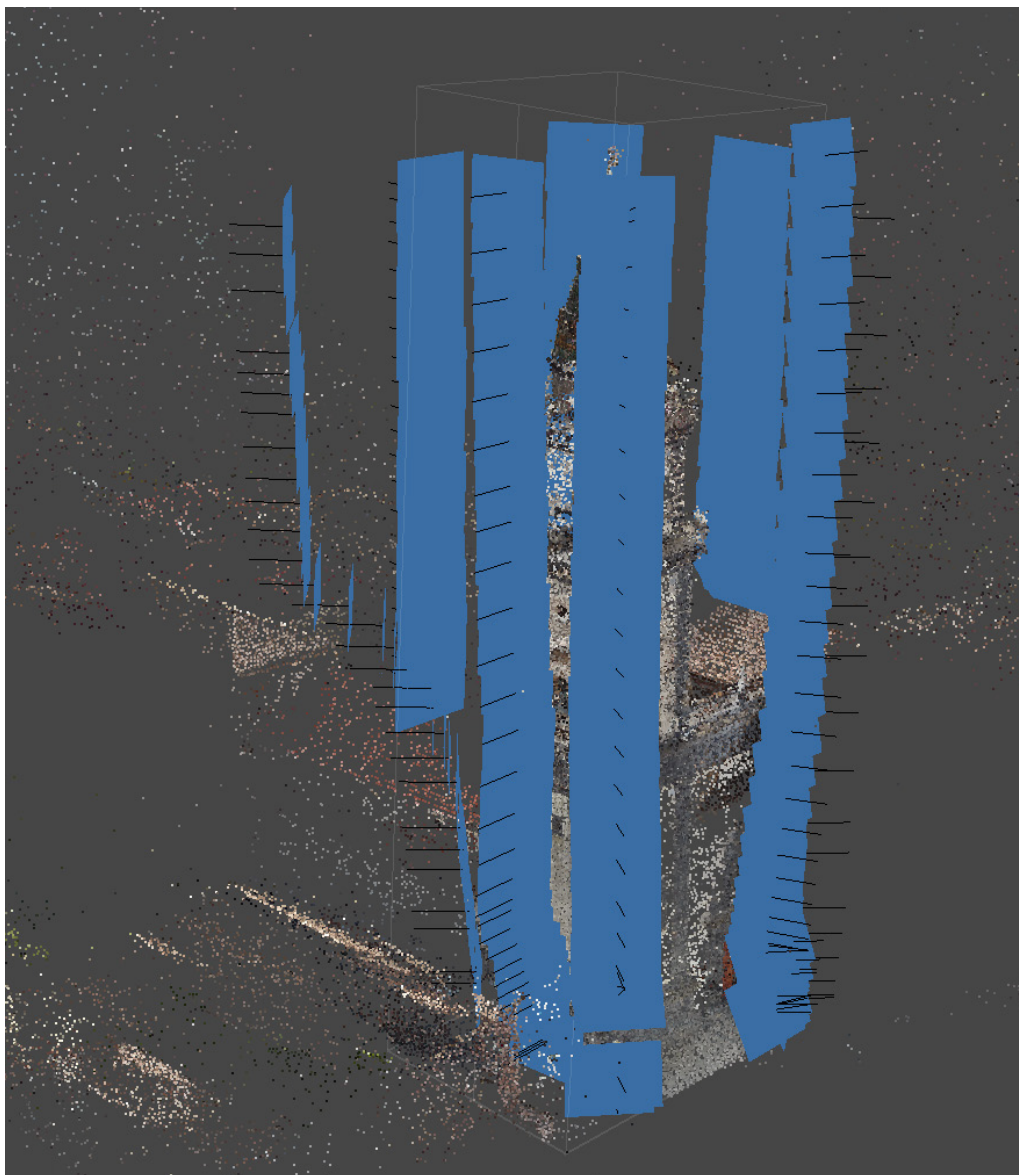


Figure 90. Camera positions during UAV-based survey of Santa Caterina.

Similarly to what was observed in the case of Acireale, the survey proved to be a fundamental tool for understanding the architectural organism. However, the safety conditions of the uppermost level did not allow direct access to the interior of the spire, limiting the possibility of acquiring data on its internal structural configuration. This limitation was partially compensated by the use of archival photographic documentation, which made it possible to integrate the information derived from the external survey.

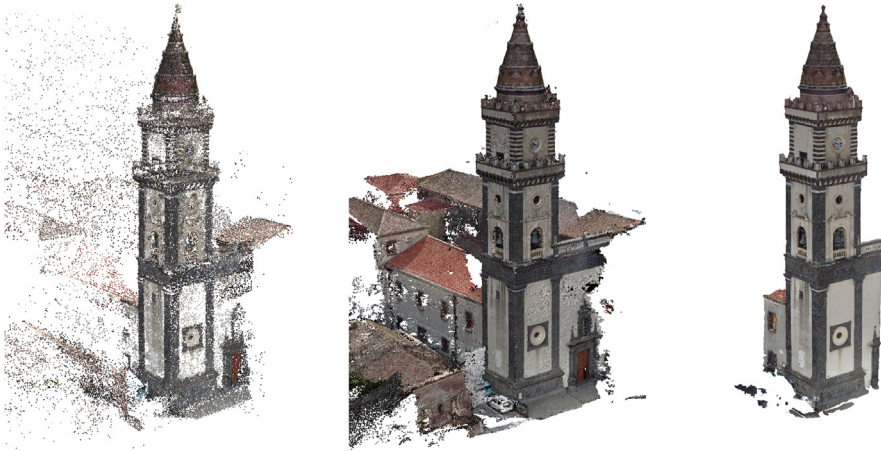


Figure 91. Three-dimensional model derived from UAV photogrammetry of Santa Caterina. Processing stages in Agisoft Metashape. From left: sparse point cloud, dense point cloud, textured mesh.



Figure 92. Detail of the photogrammetric point cloud of the spire of Santa Caterina.

Graphical Representation of Survey Outputs

The results of the survey were represented through a series of graphical outputs and three-dimensional models, aimed at illustrating the geometry and material characteristics of the architectural organism. Plans, elevations, and sections were produced, accompanied by three-dimensional models at a 1:100 scale, which are useful for the overall interpretation of the bell tower and its spatial configuration (Figures 93-94).

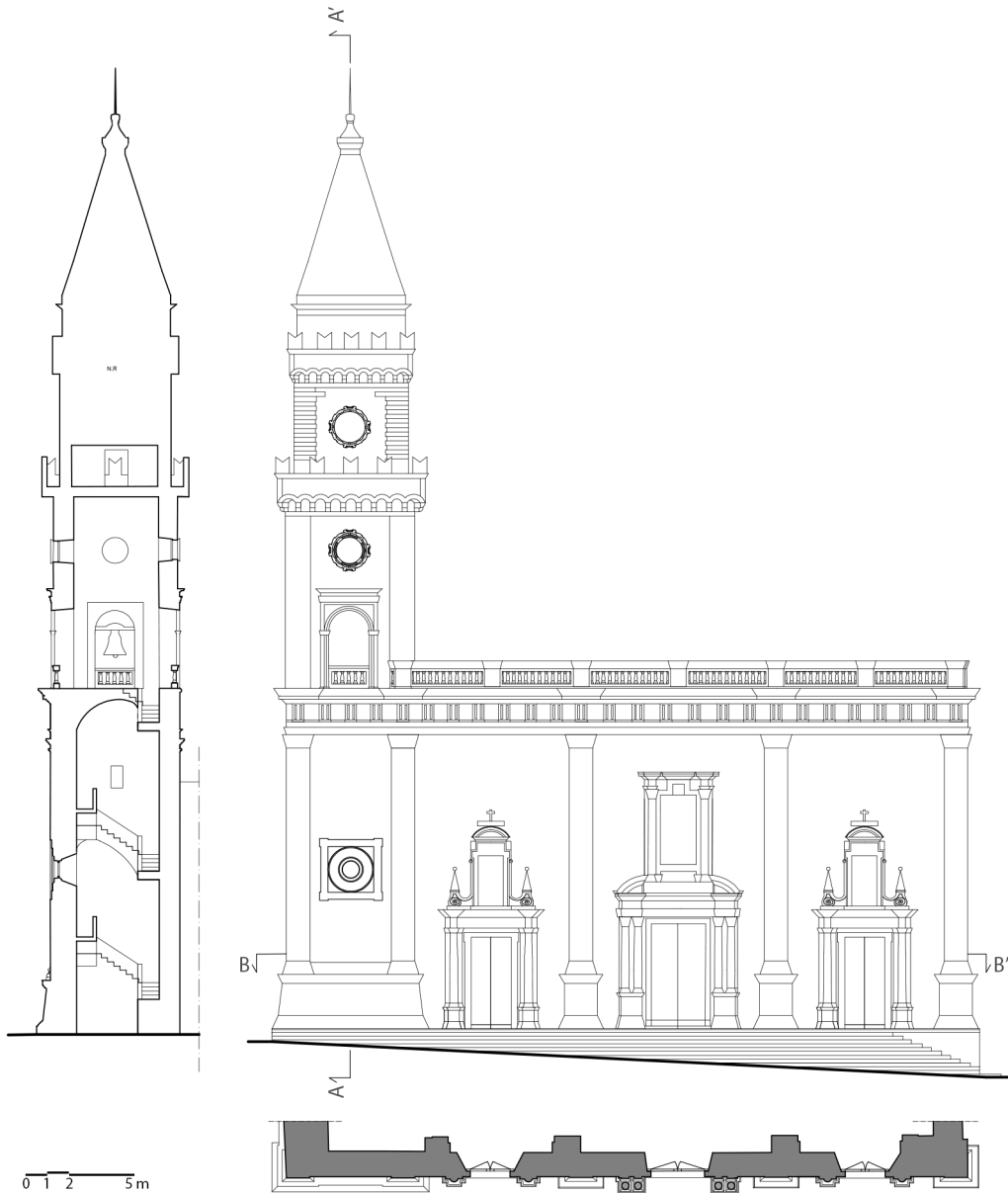


Figure 93. Two-dimensional graphical outputs of the tower of the Basilica of Santa Caterina.

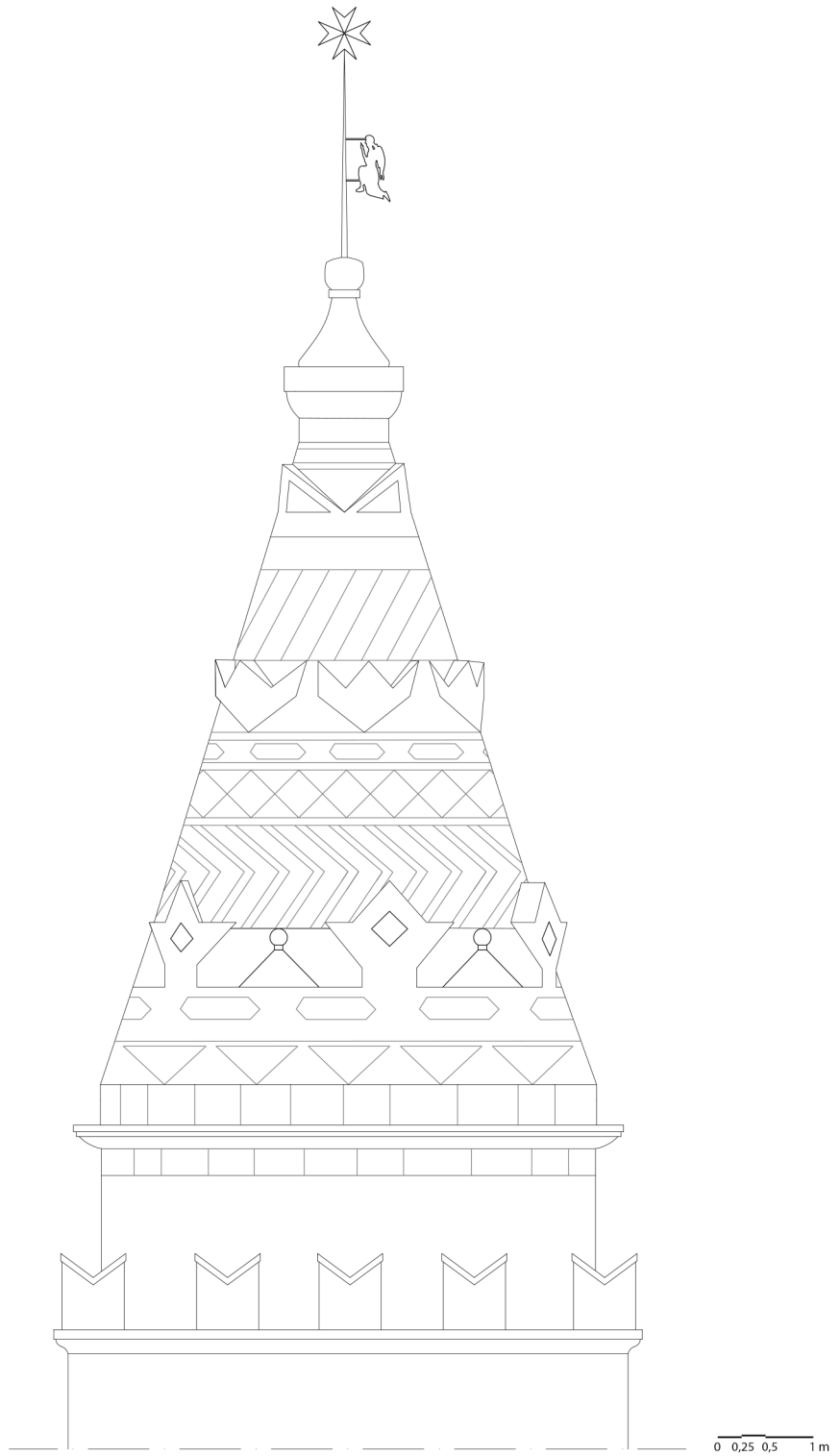


Figure 94. Schematic representation of the geometric pattern of the spire of the Basilica of Santa Caterina.

8.3.3 - The Bell Tower of the Church of Santa Maria delle Grazie in Tremestieri Etneo

Historical and Architectural Overview

The Church of Santa Maria delle Grazie is located in the hamlet of Piano Tremestieri, within the municipality of Tremestieri Etneo, and, together with Piazza Regina Margherita onto which it faces, constitutes the main spatial and social reference of the settlement (Figure 95). The building is set within a context strongly influenced by the natural dynamics of the Etnean territory, marked by seismic and volcanic events which, over the centuries, have significantly affected the urban and architectural configuration.

The construction of the church dates back to the late sixteenth century and was completed in the first half of the seventeenth century, as attested by the inscription engraved on the keystone of the bell tower arch, bearing the date 1628. Originally, the building, associated with the cult of Saint Roch, belonged to the so-called “*cordone sanitario*”, a system of structures located outside inhabited centres with the function of sanitary control during epidemics. Following the severe damage caused by the earthquake of 1693, the church was rebuilt in the early eighteenth century, assuming a configuration substantially corresponding to the present one and dedicated to Our Lady of Graces (Regione Siciliana, 1992).

Over time, the building has undergone numerous interventions of transformation and consolidation, related both to the effects of natural disasters and to maintenance re-



Figure 95. Location of the Church of Santa Maria delle Grazie in Tremestieri Etneo.

quirements. Among these, a 1929 intervention introduced a system of vaulted coverings, modifying the original configuration of the structure, followed by further works carried out between the late 1980s and the 1990s. In particular, the interventions of 1998, carried out due to the damage caused by the 1990 earthquake, led to the replacement of the vaulted coverings with a timber structure, determining the current roof configuration.

From an architectural perspective, the church presents a simple rectangular single-nave layout, terminating in an elevated presbytery. The main body is flanked laterally by the bell tower, which develops as a distinct volume yet integrated within the overall composition of the building. The architectural organism, of modest dimensions, is characterised by a sober configuration consistent with its role as a neighbourhood church, in which decorative elements are mainly concentrated in the main façade, in the worked stone portal, and in the frescoed walls of the nave.

Despite its simplicity, the bell tower constitutes the emergent element of the complex and plays a significant role in local urban perception, acting as a visual reference within the hamlet of Piano Tremestieri, particularly in relation to the presence of the spire clad in polychrome ceramics.

The Glazed Wedge-Shaped Brick Spire of the Church of Santa Maria delle Grazie

The spire of the bell tower of the Church of Santa Maria delle Grazie (Figure 96) presents a conical configuration set on a cylindrical drum, approximately 0.60 m high, which is in turn connected to the square base of the tower by means of pendentives. This solution allows the transition from the quadrangular geometry of the shaft to the conical form of the spire. The spire reaches a height of approximately 3.30 m and has a base diameter of approximately 2.20 m.

From a constructive point of view, the structure is composed of wedge-shaped bricks, presumably with a load-bearing function, characterised by a thickness that appears to be smaller than in the other analysed case studies. The intrados, visible from the level of the belfry, is defined by a thick layer of mortar that regularises the internal surface. Access to the tower allowed a direct reading of the constructive configuration of the spire and revealed the presence of timber and metal elements attributable to connection and containment systems (Figure 97). A distinctive feature is represented by the presence of an opening located at the level of the drum, which partially extends into the surface of the spire and is likely related to the need to place bells outside the tower. At the top, the spire is crowned by a metal cross (Figure 96).

The wedge-shaped bricks are most likely coated with ceramic, although it was not possible to directly verify the nature of the surface treatment. The surface of the spire presents a mixed geometric decorative pattern combining triangles, lozenges, and zig-zag motifs, characterised by the use of green, white, yellow, light blue, and brown colours (Figure 96).

About the state of conservation, the spire appears overall to be in fair condition, although some localised critical issues are evident. In particular, the presence of invasive vegetation is observed, along with localised phenomena of glaze erosion. Repair interventions are also visible, characterised by mortar infill in correspondence with missing elements, which alter the continuity of the ceramic cladding (Figure 98). Maintenance



Figure 96. Spire of the Church of Santa Maria delle Grazie.

and safety interventions on the bell tower are documented in 1989, when cleaning of the cladding, removal of organic deposits, and adjustment of the upper cross were carried out, in addition to the closure of cracks present in the structure⁸.

⁸ Archivio Soprintendenza ai Beni Culturali ed Ambientali di Catania. CT 51-2, Perizia di spesa n. 36, 27/04/1989.



Figure 97. Intrados of the spire of Santa Maria delle Grazie.



Figure 98. Visible deterioration phenomena: presence of invasive vegetation, glaze erosion, and missing ceramic elements.

Integrated Survey of the Church of Santa Maria delle Grazie and Its Tower

The survey of the Church of Santa Maria delle Grazie was conducted on the entire architectural organism, including both the main building and the bell tower, with the aim of acquiring comprehensive geometric documentation of the structure.

Data acquisition was carried out using laser scanning technology, employing the Leica BLK360 instrument for surveying both interior spaces and external areas. This choice allowed a complete and homogeneous coverage of the architectural organism, ensuring an adequate level of detail in the representation of the geometries. For the survey of the bell tower, the mobile system BLK2GO, based on SLAM technology, was also employed, allowing rapid and effective acquisition of vertical spaces and areas that are difficult to access, integrating the data obtained from the static survey. The survey campaign included a total of 26 scans, of which 2 were acquired using SLAM technology, for a total

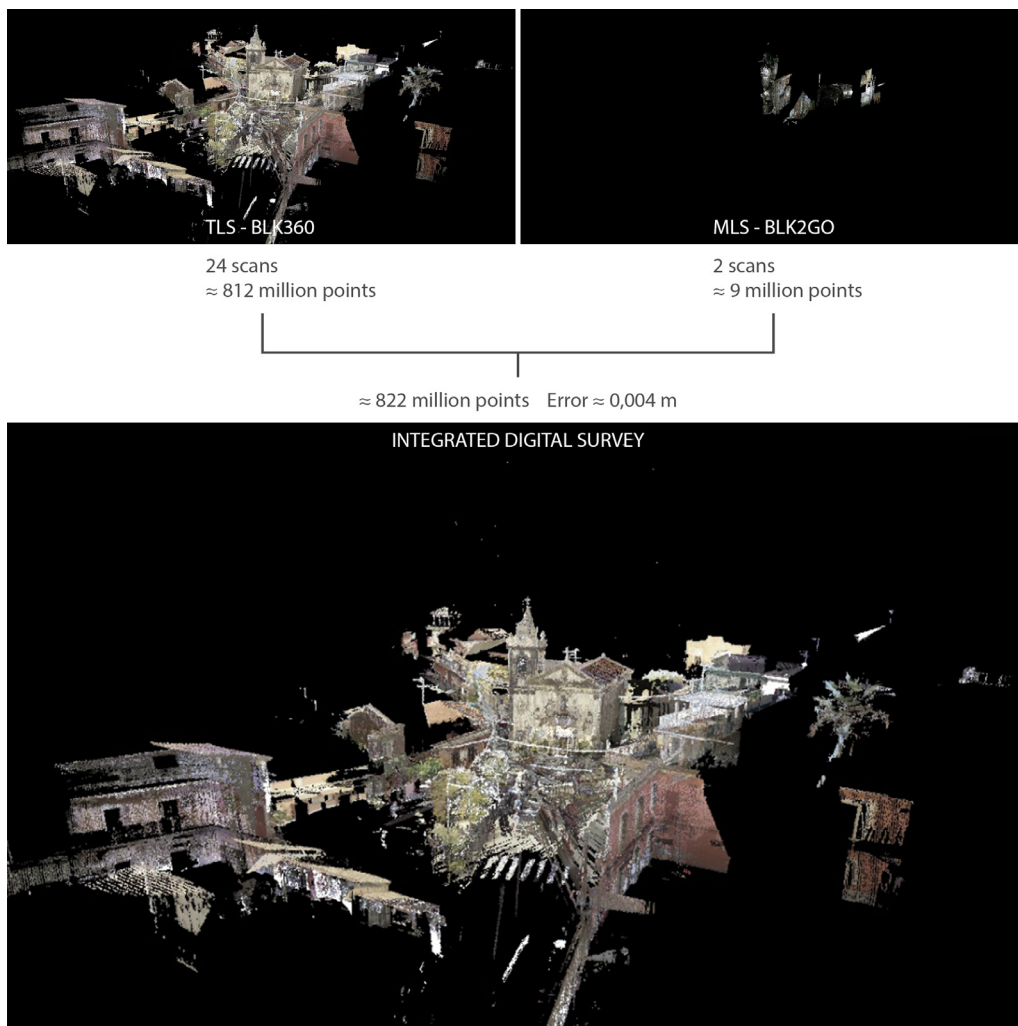


Figure 99. Point clouds obtained from surveys of Santa Maria delle Grazie using two laser scanners: BLK360 and BLK2GO.

of approximately 820 million points (Figures 99-100-101).

The absence of additional acquisition techniques, such as photogrammetric survey, resulted in a methodological approach based exclusively on laser scanning data. This approach is consistent with the dimensional and morphological characteristics of the building, while still allowing an adequate representation for documentation and analysis purposes.



Figure 100. Position of BLK360 scan stations (in yellow) and trajectory of the mobile laser scanner BLK2GO (in red) in Santa Maria delle Grazie.

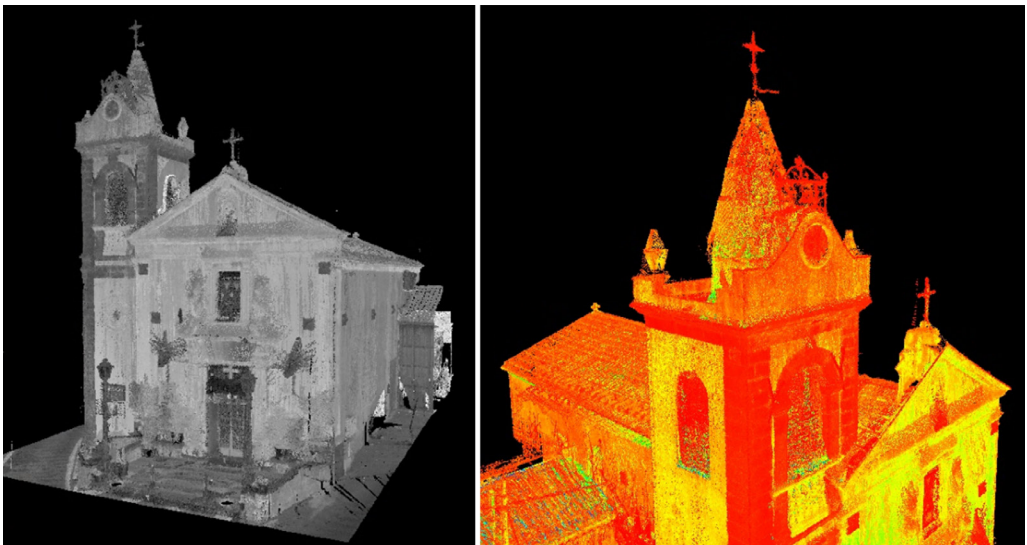


Figure 101. Point cloud of the Church of Santa Maria delle Grazie.

Graphical Representation of Survey Outputs

The acquired data were processed to obtain both graphical and three-dimensional representations of the architectural organism, supporting the documentation and analysis of the case study. The outputs produced include two-dimensional representations and three-dimensional models derived from the point cloud, allowing an integrated interpretation of the geometric and constructive characteristics of the church and the bell tower (Figure 102).

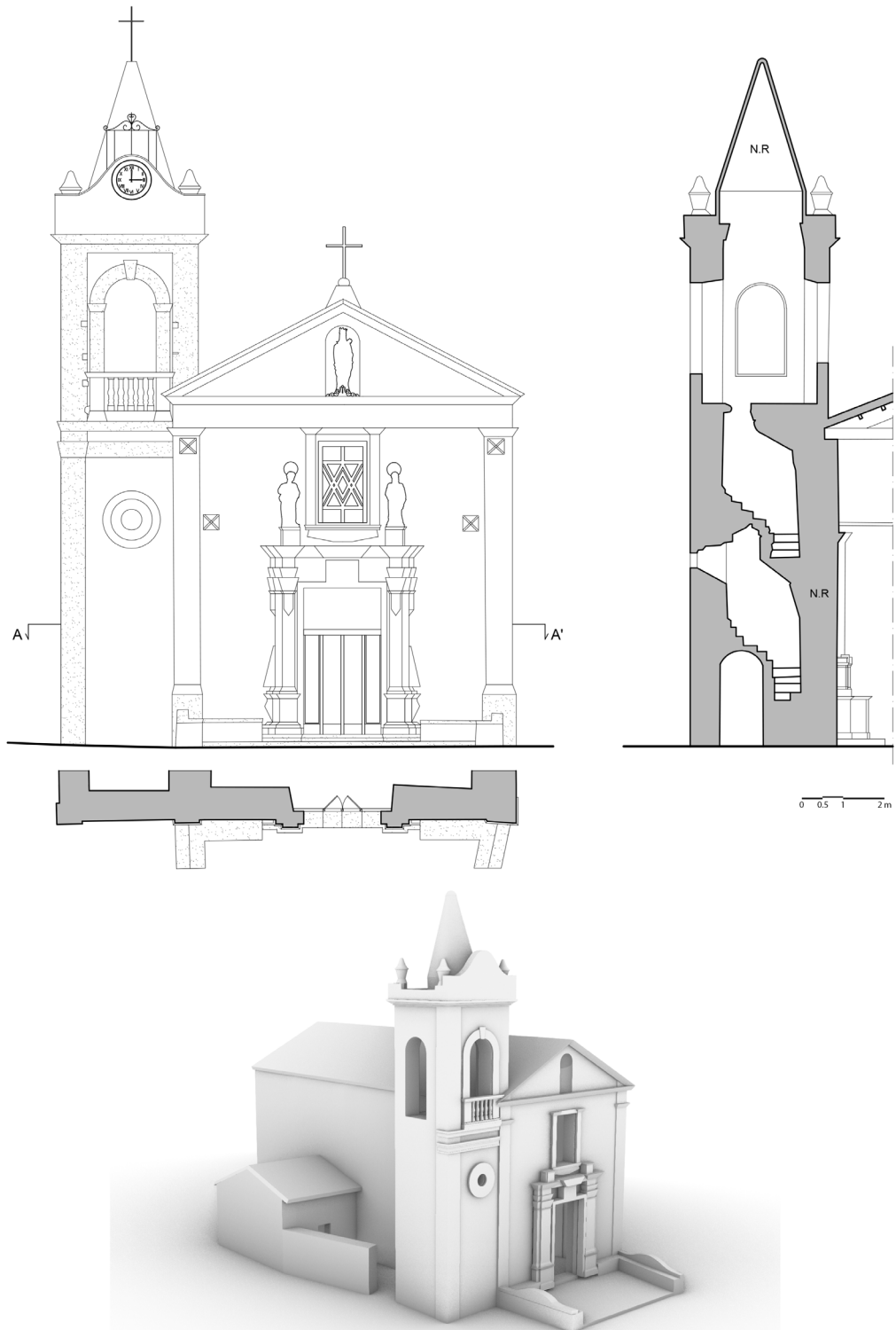


Figure 102. Two-dimensional and three-dimensional graphical outputs of the tower of the Church of Santa Maria delle Grazie.

8.3.4 - The Bell Tower of the Church of San Pietro in Adrano

Historical and Architectural Overview

The Church of San Pietro is located in the historic centre of Adrano, within an urban context characterised by a significant historical stratification within the consolidated settlement fabric, assuming a relevant role in the configuration of the urban space (Figure 103).

The origins of the church can be traced back to an early phase, subsequently subject to transformations and enlargements that modified its original configuration over time. As with most buildings in the Etnean area, the structure suffered severe damage during the earthquake of 1693, an event that also led to the collapse of the bell tower, which was later rebuilt in 1734 (Scalisi, 2002). Over time, the building has undergone further interventions, including a request submitted in 1987 to the Soprintendenza for the repair of the spire, which was still damaged by the wartime events of 1943, as well as ordinary and extraordinary maintenance works carried out in 1991 following the presence of cracks in the bell tower⁹. More recently, in 2020, restoration interventions for the entire complex were planned, aimed at repairing the damage caused by the 2018 earthquake, including works affecting the spire¹⁰.

⁹ Archivio Soprintendenza ai Beni Culturali ed Ambientali di Catania. CT 6-19, *Lavori di manutenzione ordinaria e straordinaria alla Chiesa S. Pietro, 1991 prot. N. 1095 – Preventivo dei lavori.*

¹⁰ Archivio Chiesa S. Pietro. *Restauro della Chiesa di San Pietro in Adrano, finalizzato alla riparazione dei danni provocati dal sisma del 6 ottobre 2018, con interventi di consolidamento. Interventi aggiuntivi sulla copertura a cuspide del campanile – Relazione sugli interventi, April 2020.*



Figure 103. Location of the Church of San Pietro in Adrano.



Figure 104. Photographs of February 1955 of the Church of San Pietro. Source: Photographic archive of the Soprintendenza per i Beni Culturali e Ambientali di Catania, CT 6-19, photos n. 6393, 6394, 6392.

From an architectural perspective, the church has a Latin-cross plan with a single nave, covered by a barrel vault with lunettes. The transept is characterised by lateral arms covered with pavilion vaults, while at the crossing between the nave and the transept a dome is set, defining a central space of compositional relevance.

The bell tower is positioned laterally with respect to the façade (Figure 104), with direct access from the nave, configuring itself as a volume integrated with but distinguishable from the main body of the church. The spire, unlike those previously analysed, presents a surface only partially clad in ceramic wedge-shaped bricks.

The Glazed Wedge-Shaped Brick Spire of the Church of San Pietro

The spire of the bell tower of the Church of San Pietro presents a conical configuration and is set directly above the belfry (Figure 105). The spire reaches a height of approximately 8.00 m and has a base diameter of approximately 4.50 m, configuring itself as an element of considerable size in relation to the overall scale of the building.

Unlike the previously analysed spires, the ceramic cladding is limited to specific decorative elements that define an articulated compositional scheme. In particular, the surface of the spire is divided into four main fields by the presence of four vertical bands composed of five superimposed courses of glazed brick, characterised by a polychromy alternating brown, yellow, white, green, and blue. These bands articulate the surface with a regular rhythm, defining a geometric subdivision of the spire. The four resulting fields are plastered and contain additional decorative inserts in ceramic brick, which contribute to enriching the overall design of the cladding. Near the top, the spire is also characterised by the presence of eight courses of glazed bricks laid on edge, forming a continuous crowning band that emphasises the closure of the volume. The wedge-shaped bricks used for this spire are hollow on one side and present grooves on the other (Figure 106).

From a constructive perspective, it was not possible to investigate in detail the internal configuration of the spire, as observation from the intrados did not allow a clear reading of the structure (Figure 107). However, the distribution of the ceramic elements, limited to specific portions of the surface, suggests a distinction between the load-bearing structure and the cladding, unlike what has been observed in other case studies



Figure 105. Spire of the Church of San Pietro.



Figure 106. Glazed wedge-shaped bricks of the spire of San Pietro.



Figure 107. Intrados of the spire of San Pietro.

where wedge-shaped bricks also form part of the structural system. Furthermore, some photographs of a consolidation intervention carried out in 2020 suggest that at least the outer portion of the spire structure is made of stone masonry.

Regarding the state of conservation, the spire appears overall to be in fair condition. The main deterioration phenomena observed are related to the presence of organic deposits, particularly guano, and to localised phenomena of glaze erosion affecting the surface of the glazed bricks (Figure 108).

The restoration intervention carried out in 2020 significantly affected the spire. Following the removal of invasive vegetation, carried out both manually and through biocidal treatments, structural consolidation operations were performed through the application of GFRP (Glass Fiber Reinforced Polymer) meshes, along with masonry repairs using lime-based mortars. At the same time, the plaster was renewed using *cocciopesto* mortar and the uppermost element was restored. As regards the ceramic cladding, the intervention involved the reassembly and fixing of existing elements, including the dismantling and reinstallation of unstable portions and localised consolidation through mortar injections¹¹. It is noteworthy that the intervention was carried out without the

¹¹ Archivio Chiesa S. Pietro. *Restauro della Chiesa di San Pietro in Adrano, finalizzato alla riparazione dei danni provocati dal sisma del 6 ottobre 2018, con interventi di consolidamento. Interventi aggiuntivi sulla copertura a cuspide del campanile – Relazione sugli interventi, April 2020.*



Figure 108. Visible deterioration phenomena: presence of guano and glaze erosion.

integration of new ceramic elements, relying exclusively on existing materials. This choice has resulted in the loss of some parts of the original decorative pattern, which is no longer fully legible, but has ensured the preservation of the material authenticity of the surface.

Integrated Survey of the Church of San Pietro and Its Tower

The survey of the Church of San Pietro was conducted on the entire architectural organism, including both the main building and the bell tower, with the aim of acquiring comprehensive geometric documentation of the structure.

Data acquisition was carried out using laser scanning technology, employing the Leica BLK360 instrument for surveying both interior and exterior spaces. The survey campaign included a total of 20 static scans, integrated by 1 mobile acquisition using the BLK2GO system for the survey of the bell tower, for a total of approximately 736 million points (Figures 109-110-111). This configuration allowed a complete and homogeneous coverage of the architectural organism, ensuring an adequate level of detail in the representation of the geometries.

In parallel, a photogrammetric campaign was carried out using a DJI Mini 2 drone with integrated camera, aimed at documenting the external surfaces of the spire. A total of 154 images were acquired and subsequently processed using Agisoft Metashape software, in order to generate a dense point cloud consisting of approximately 39 million points and a three-dimensional mesh composed of approximately 2.6 million triangles (Figures 112-113). This integration enabled a more detailed representation of the material and decorative characteristics of the spire (Figure 114).

The data processing operations included the registration and alignment of laser scans, the generation of the overall point cloud, and the subsequent integration with the photogrammetric data, forming the basis for the following phases of graphical representation and analysis.

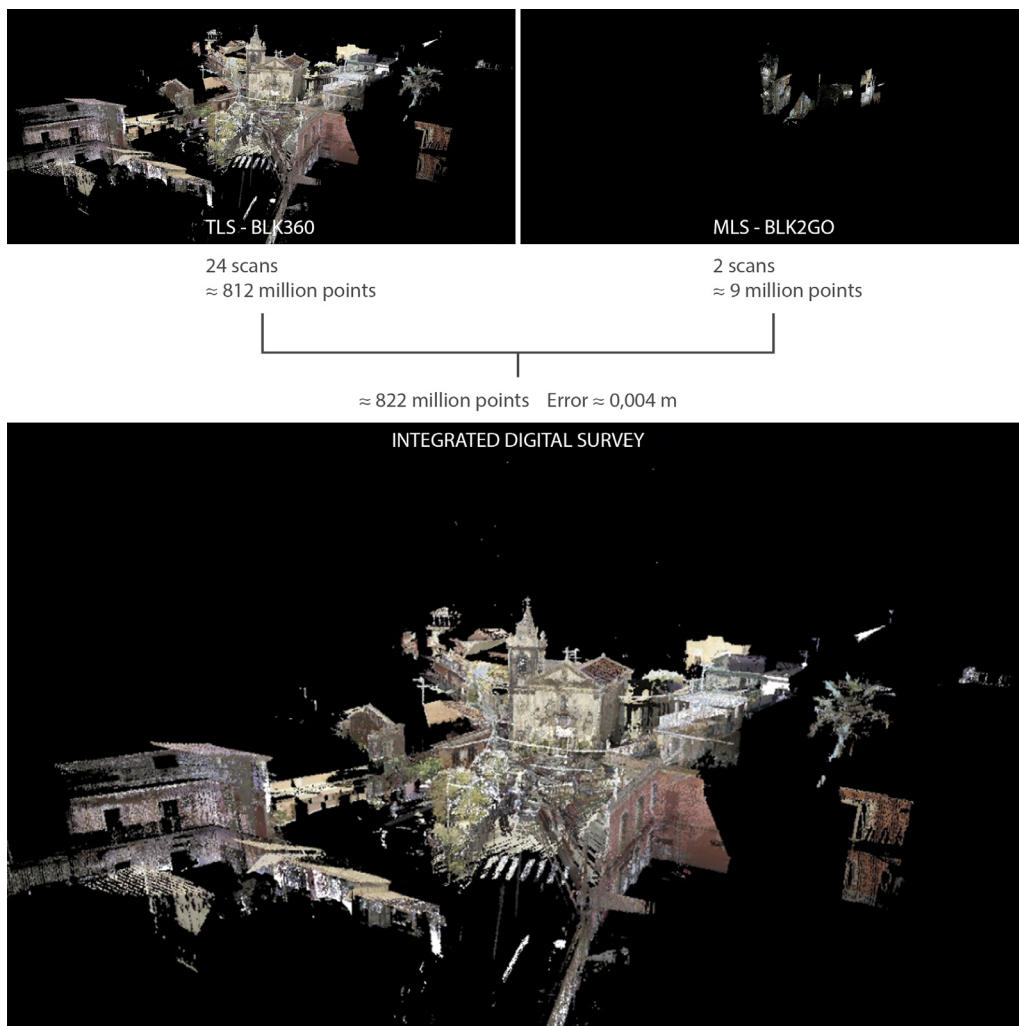


Figure 109. Point clouds obtained from surveys of San Pietro using two laser scanners: BLK360 and BLK-2GO.

In order to further investigate the geometric and material characteristics of the ceramic elements, a detailed survey was also carried out on five bricks representative of the decorative pattern of the spire, selected according to their different colours. The acquisition was performed using a structured-light laser scanner SCANTECH iReal 2E, which allowed the generation of high-resolution three-dimensional models of the individual elements (Figure 115). This operation made it possible to document more precisely the geometry of the components and the surface characteristics of the ceramic cladding, providing an additional level of analysis with respect to the survey of the entire architectural organism.

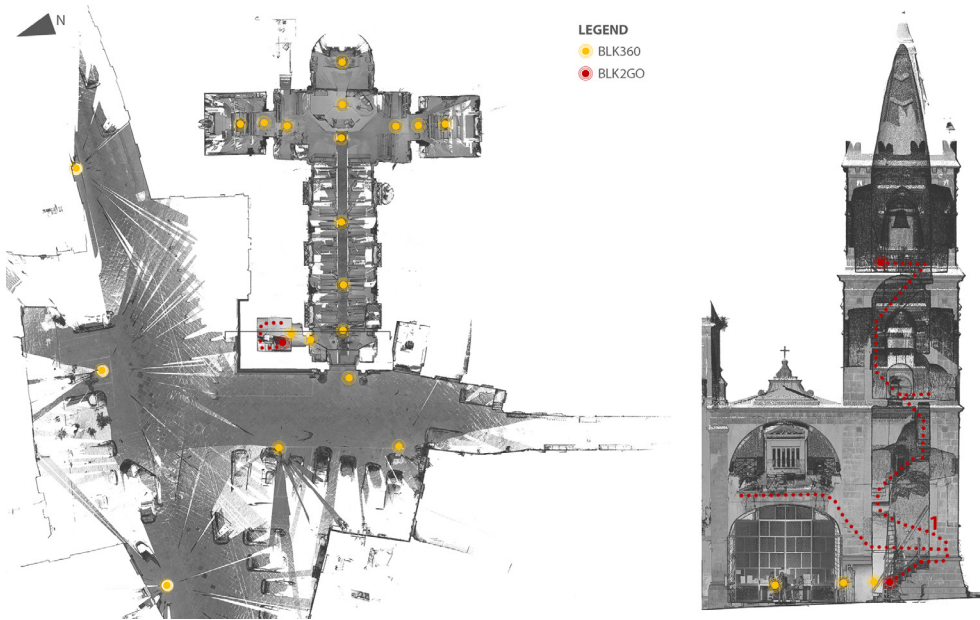


Figure 110. Position of BLK360 scan stations (in yellow) and trajectory of the mobile laser scanner BLK2GO (in red) in San Pietro.

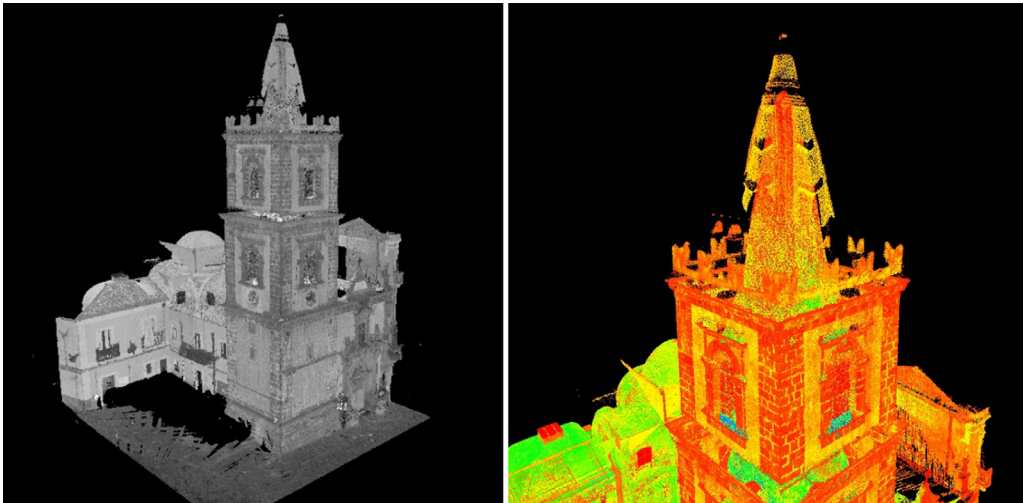


Figure 111. Point cloud of the Church of San Pietro.

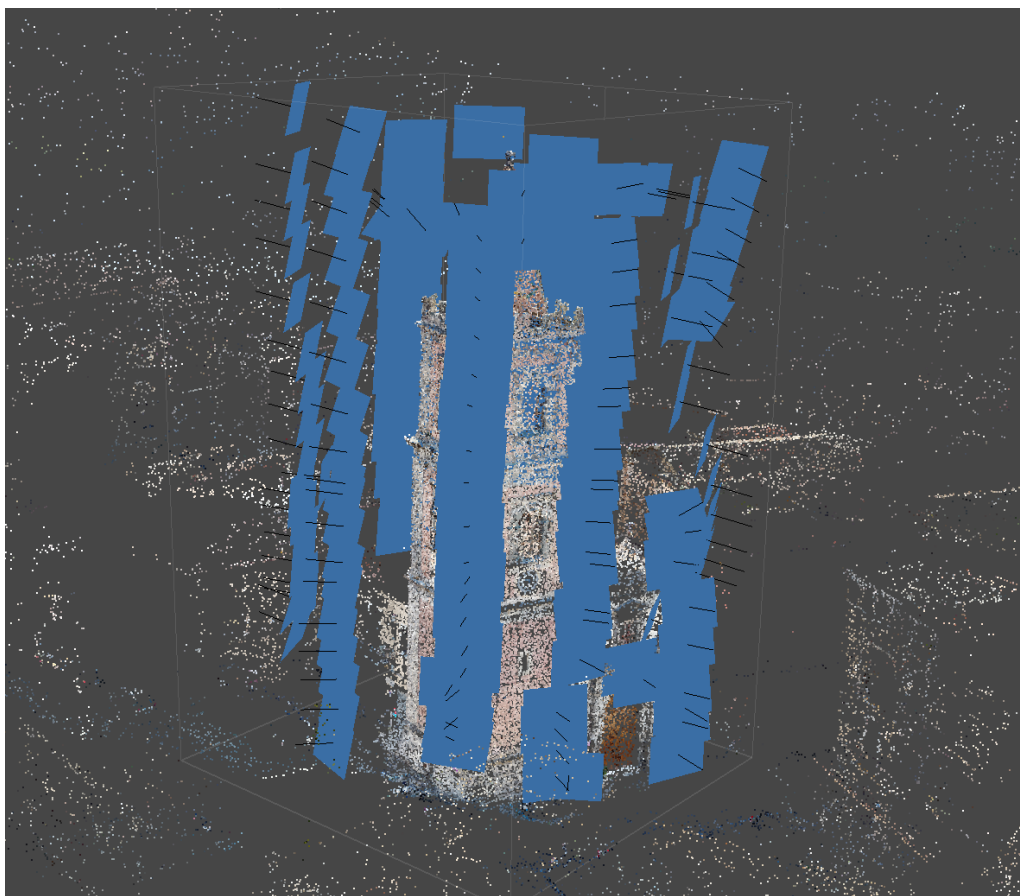


Figure 112. Camera positions during UAV-based survey of San Pietro.



Figure 113. Three-dimensional model derived from UAV photogrammetry of San Pietro. Processing stages in Agisoft Metashape. From left: sparse point cloud, dense point cloud, textured mesh.



Figure 114. Detail of the photogrammetric point cloud of the spire of San Pietro.

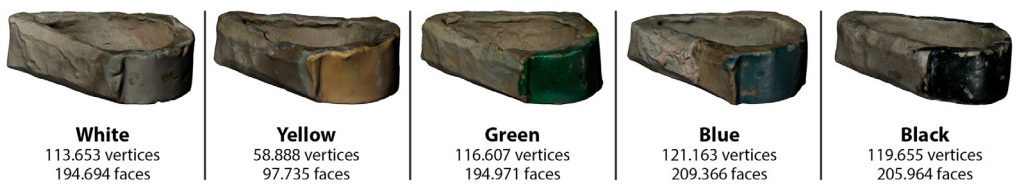


Figure 115. Mesh models of the five surveyed bricks from the spire of San Pietro.

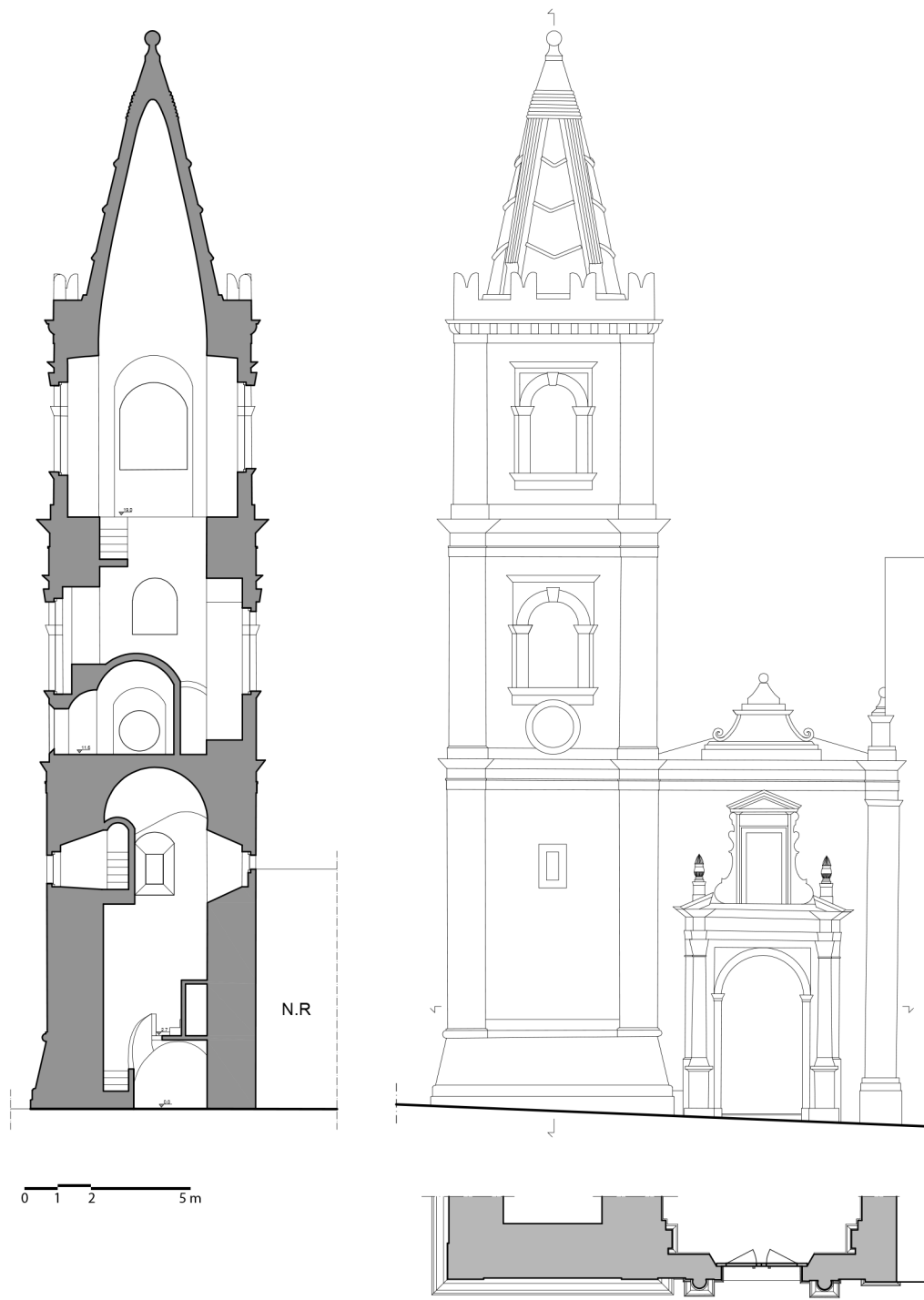


Figure 116. Two-dimensional graphical outputs of the tower of the Church of San Pietro.

Graphical Representation of Survey Outputs

The acquired data were processed to obtain graphical representations of the architectural organism, supporting the documentation and analysis of the case study. The outputs produced include plans, elevations, and sections derived from the point cloud (Figure 116), allowing an integrated interpretation of the geometric and constructive characteristics of the church and the bell tower, with particular attention to the configuration of the spire.

8.3.5 - Comparison of Survey Methodologies across the Case Studies

The survey of the bell towers and their spires was conducted according to a unified methodological framework, based on the integration of different and complementary acquisition techniques. This approach was adapted in each case study according to the specific operational conditions, without modifying the underlying methodological structure, but adjusting its application to the characteristics of the investigated object.

Among the main factors influencing the acquisition strategies, the scale of the architectural organism played a decisive role. As shown in Figure 117, the analysed towers exhibit significant dimensional differences, which are directly reflected in the operational choices. In particular, in cases characterised by greater vertical development and complexity, such as the Basilica of Maria SS. Annunziata in Acireale and the Basilica of Santa Caterina Alessandrina in Pedara, it was necessary to integrate instruments with different characteristics, combining the compact BLK360 laser scanner with the Leica P30 system, which is characterised by a longer range and is suitable for the acquisition of large-scale geometries. In smaller-scale cases, such as Tremestieri Etneo, the use of the BLK360 alone proved sufficient, due to the greater manoeuvrability of the instrument.

In all analysed cases, terrestrial laser scanning constituted the basis of the acquisition process, ensuring complete and coherent geometric documentation. This technology was complemented by the use of mobile systems based on SLAM technology, employed for the acquisition of vertical spaces and internal paths within the towers, characterised by limited accessibility. UAV-based photogrammetry was instead introduced in cases where it was necessary to acquire the external surfaces of the spires in greater detail, particularly for the documentation of the ceramic cladding and decorative patterns. A summary of the techniques employed in the different case studies is provided in Table 16.

The comparison between the case studies highlights how these techniques were not used as alternatives, but rather in different combinations within the same methodological framework. In particular, the case of the Basilica of Maria SS. Annunziata in Acireale represents the most extensively investigated and documented example, in which the integration of techniques allowed a high level of detail to be achieved both at the architectural scale and at the scale of the ceramic cladding. In the case of Pedara, the approach remains similar, although with some limitations related to access conditions. Tremestieri Etneo represents a case in which, due to the reduced scale and greater simplicity of the architectural organism, the survey was conducted with a more essential configuration, which nonetheless proved adequate for the intended knowledge objectives. Finally, in the case of Adrano, the integration of techniques was specifically oriented towards the

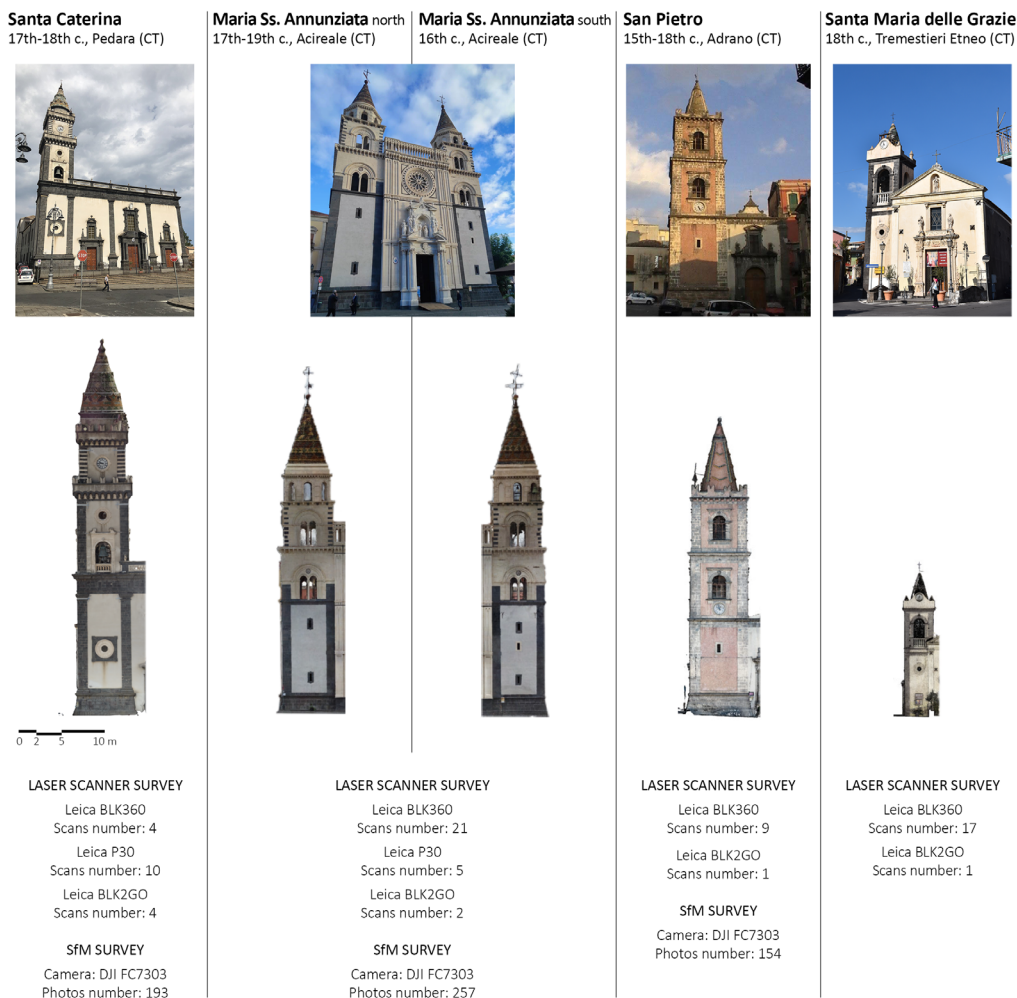


Figure 117. Comparison between case studies: summary of acquisition data.

analysis of the spire, in relation to its typological and decorative specificities.

The differences observed do not define distinct methodological approaches, but rather represent an operational modulation of a shared method, which adapts to the conditions of the context while maintaining its fundamental principles. The survey can therefore be understood as a scalable and flexible process, capable of operating at multiple levels of detail and of integrating tools and techniques according to the requirements of the analysis.

Table 16. Survey techniques employed in the case studies.

Case study	P30 (TLS)	BLK360 (TLS)	BLK2GO (MLS)	SfM
Acireale	✓	✓	✓	✓
Pedara	✓	✓	✓	✓
Tremestieri		✓	✓	
Adrano		✓	✓	✓

8.4 - Tower Cataloguing Record

The documentation of the analysed towers was supported by the development of a cataloguing documentation sheet aimed at the systematic collection and organisation of information relating to the individual artefacts. The use of such a tool makes it possible to structure descriptive, architectural, and morphological data in a consistent manner, facilitating comparability between the different case studies.

The definition of the sheet is part of the collaboration established with the Istituto Centrale per il Catalogo e la Documentazione (ICCD) for the development of an ontological model dedicated to the cataloguing of towers. The structure of the record was defined in accordance with the cultural heritage cataloguing system developed by the ICCD, which provides specific descriptive models for different types of assets.

Within the ICCD Cataloguing Standards, the “Tower” cataloguing record is included in the specialist module “Religious Architecture”, one of the disciplinary categories of the Asset Type “Architecture” within the sector “Architectural and Landscape Heritage”. The diagram in Figure 118 illustrates the structure of the ICCD Cataloguing Standards up to the model for the tower.

The conceptual structure adopted for the description of the tower has, however, been defined in such a way that it can also be applied to towers not necessarily belonging to religious complexes, thus allowing a more general description of this architectural typology. In line with this approach, the record used in the present research has been organised to include, in a concise and structured form, the main information relating to the architectural and morphological characteristics of the analysed towers.

The “Tower” record is organised into several thematic sections, each dedicated to recording specific categories of information relating to the analysed artefacts. A first section includes identification, location, functional, and relational data useful for defining the spatial context of the tower and linking the artefact to its settlement context, for example the mode of access to the tower, its possible inclusion within a system of towers, or its relationship with the building or architectural complex to which it belongs. This section also includes information relating to the description of the main geometric and morphological characteristics of the tower, such as the height of the structure, plan development, proportional relationships between parts, and discontinuities between elements.

A further group of fields is dedicated to the description of the architectural characteristics and constituent elements of the tower, including, for example, vertical structures, horizontal systems, floors, ceilings, auxiliary structural elements, vertical circulation elements, openings, and so on. For each of these, information relating to materials and construction techniques is also included, allowing the main solutions adopted in the construction of the artefact to be recorded.

Regarding the covering, the spire is, at this stage, considered as one of the constituent elements of the tower and is described mainly from a morphological and material perspective, through the indication of its formal configuration, for example conical, spire-like, or bulbous, and the materials used. A more detailed articulation of the description, including decorative aspects of the spires, represents a possible future development of the documentation model.

The record also includes sections dedicated to existing documentation and to bibliographic and web references, useful for collecting the main sources available on the analysed artefacts.

From the point of view of data structure, the record combines free-text fields and fields based on controlled vocabularies. The latter have been introduced to ensure greater terminological consistency in the recording of information and to reduce descriptive ambiguity that may arise from the use of exclusively textual fields. Controlled vocabulary fields refer to structured sets of terms that allow recurring characteristics of towers to be described in a consistent way, such as morphological configuration, relationships between parts, access systems, or materials used. The use of such vocabularies not only standardises the description of the artefacts, but also facilitates subsequent querying and comparison between different case studies, making the record a useful tool both for

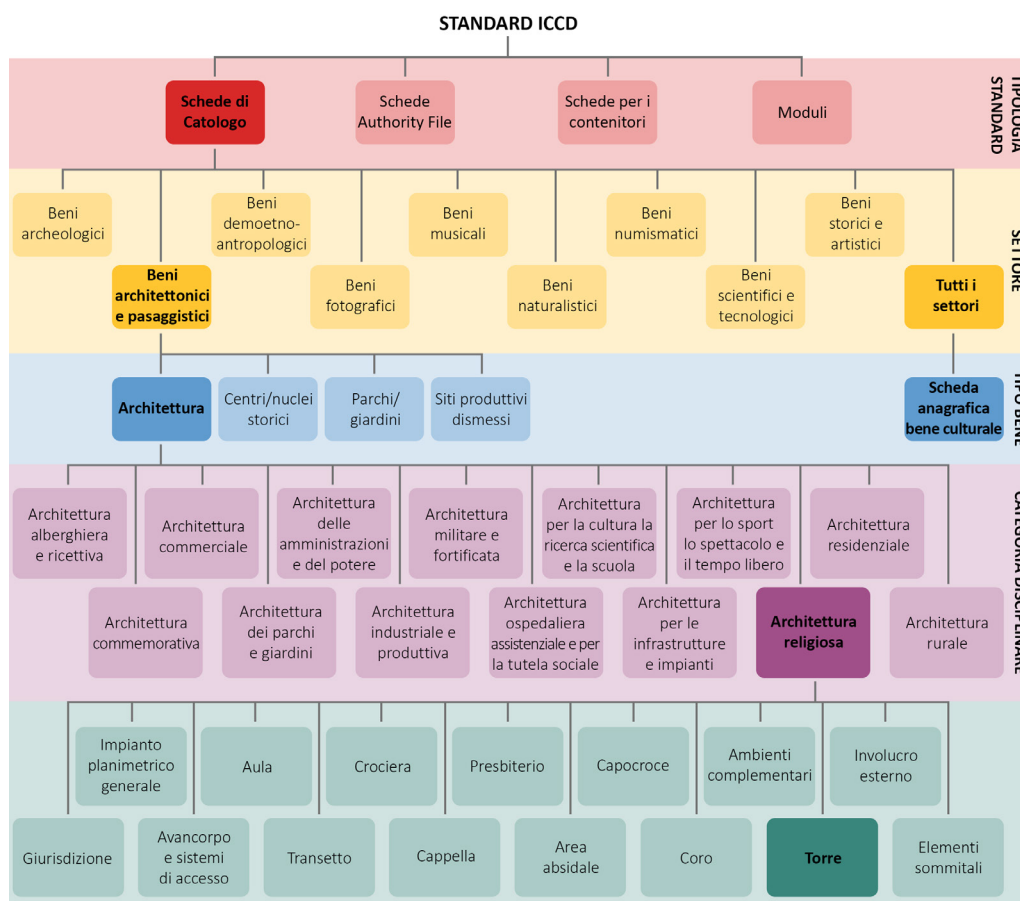


Figure 118. Structure of the ICCD Cataloguing Standards up to the “Tower” record. The terminology is kept in Italian in accordance with the official ICCD nomenclature. Highlighted boxes indicate the path followed in the present research: *Schede di Catalogo* (Catalogue Records), *Beni architettonici e paesaggistici* (Architectural and Landscape Heritage), *Architettura* (Architecture), *Architettura religiosa* (Religious Architecture), and *Torre* (Tower).

documentation and for the comparative analysis of the considered towers.

As a complement to the documentation of the case studies, cataloguing sheets relating to the towers were compiled. The sheets were completed using the documentation model developed within the research and allow the main information relating to the architectural, morphological, and material characteristics of the artefacts to be collected in a structured form. By way of example, the cataloguing record of the south bell tower of the Cathedral of Acireale is presented in the Appendix.

8.5 - Integration of the Geometric Model with Structural Analysis

The digital surveys carried out on the case studies presented in the previous sections provided a detailed and metrically reliable representation of the geometry of the analysed towers. The point clouds obtained through the integrated survey methodology constituted the starting point for the development of simplified geometric models suitable for structural analysis¹² (Figure 119).

From the processed point clouds, orthophotos of elevations as well as vertical and horizontal sections were extracted. These graphical documents, combined with historical research and direct observation of the buildings, supported the interpretation of the architectural configuration of the towers, including the identification of construction techniques, materials and structural layout, which represent fundamental parameters for the development of reliable structural models (Micelli et al., 2020; Pieraccini et al., 2014).

In order to prepare the structural models for numerical analysis, the geometries derived from the survey were simplified, removing secondary architectural details while

¹² This subsection is based on the framework proposed by author in Contrafatto et al. (2026).

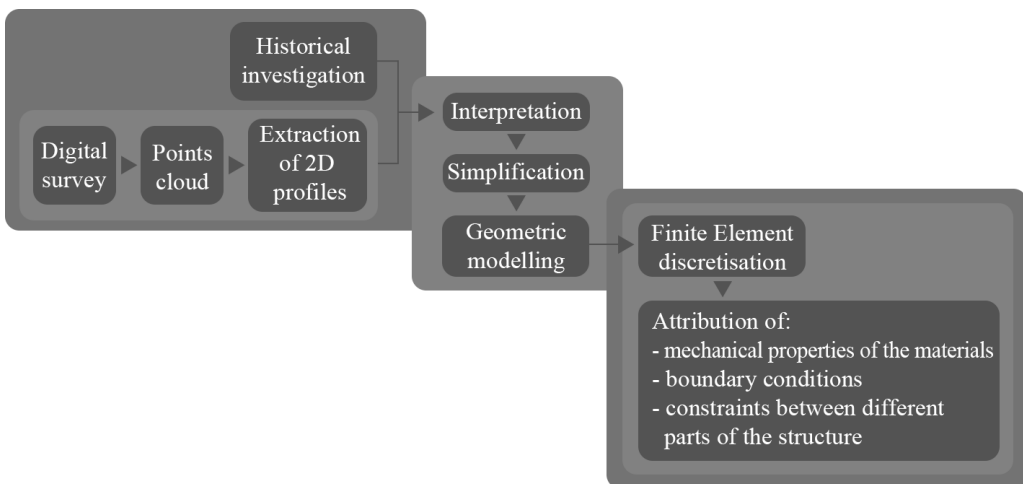


Figure 119. Workflow adopted for the integration of digital survey data into the structural modelling process.

preserving the main dimensional and morphological characteristics. This simplification process is commonly adopted in the generation of finite element models of historic masonry structures, allowing the creation of computational models that retain the essential geometric features while ensuring manageable levels of complexity (Aita et al., 2017; Scamardo et al., 2022).

Starting from the extracted sections and elevations, three-dimensional models of the towers were reconstructed in a CAD environment through solid modelling operations (Figure 120). These models constitute the geometric basis for subsequent structural simulations in FEM environment and vulnerability assessments, as commonly carried out in the analysis of slender masonry structures and historic towers (Shakya et al., 2016).

The resulting geometric models were then exported in interoperable formats and imported into the structural analysis software Midas FEA NX, where they were discretised through 3D solid finite elements (Figure 121). The mesh, composed of tetrahedral elements, allows the geometric characteristics of the towers to be represented with sufficient accuracy while maintaining an appropriate balance between computational efficiency and modelling detail. Among the various modelling strategies adopted for masonry structures, the use of three-dimensional solid finite elements makes it possible to obtain numerical results that closely reflect the actual geometry of the buildings.

For the purposes of the analyses carried out in this research, the towers were modelled as isolated structures, neglecting the structural interaction with the adjacent church buildings. The boundary conditions were therefore simplified by assuming a fixed base condition, approximating the structural behaviour of the towers to that of cantilever structures. This modelling assumption is commonly adopted in preliminary analyses of slender masonry towers and allows the global dynamic behaviour of the structures to be investigated.

The models were subdivided into different solid components corresponding to the main architectural parts of the towers. This subdivision enables the assignment of different materials and mechanical properties to the various portions of the structure in subsequent phases of model refinement, reflecting the stratified nature of historic constructions characterised by multiple building phases. In this preliminary phase, however, the structures were modelled assuming a homogeneous and isotropic material in order to perform initial modal analyses.

In order to account for the influence of non-structural elements on the dynamic response of the towers, both distributed and concentrated loads were introduced and converted into equivalent masses within the numerical model. These loads represent the contribution of architectural and construction components that do not directly participate in the structural resistance but nonetheless influence the global dynamic behaviour of the structure. For example, the floors located at different heights, including those at the level of the belfry, were modelled as equivalent loads acting on the perimeter masonry walls in all cases. The load-bearing areas were identified by observing the direction of the floor framing. As regards the bell apparatus, equivalent concentrated masses were considered and applied at the support points of the bell-supporting structure.

Given the high level of geometric accuracy ensured by the digital survey, geometric uncertainty within the modelling process can be considered negligible. The main un-

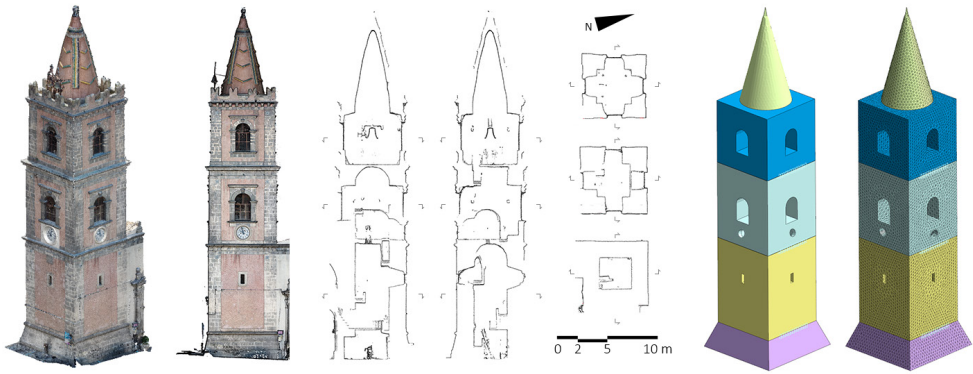
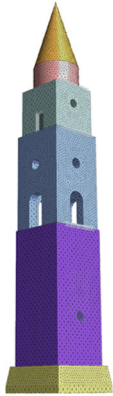


Figure 120. Generation of the structural models: point clouds obtained from digital surveys, extraction of two-dimensional drawings and development of three-dimensional models prepared for finite element analysis.

Santa Caterina
17th-18th c., Pedara (CT)

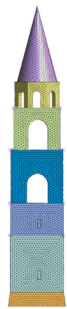
Bell tower dimensions:
h = 44.6 m h' = 35.9 m
b = 6.2x6.7 m
h'/b=5.8



N. of Nodes: 39471
N. of Elements: 177463
N. of DOFs: 119766

Maria Ss. Annunziata north
17th-19th c., Acireale (CT)

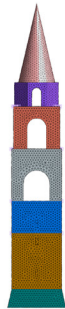
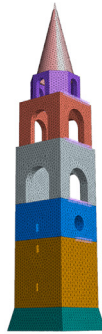
Bell tower dimensions:
h = 37.1 m h' = 28.4 m
b = 6.4x6.5 m
h'/b=4.4



N. of Nodes: 30098
N. of Elements: 133189
N. of DOFs: 92070

Maria Ss. Annunziata south
16th c., Acireale (CT)

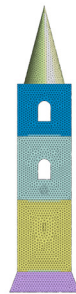
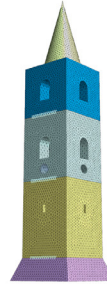
Bell tower dimensions:
h = 37.1 m h' = 28.4 m
b = 6.3x6.1 m
h'/b=4.6



N. of Nodes: 29026
N. of Elements: 127338
N. of DOFs: 88662

San Pietro
15th-18th c., Adrano (CT)

Bell tower dimensions:
h = 35.1 m h' = 25.7 m
b = 6.8x6.7 m
h'/b=3.8



N. of Nodes: 42546
N. of Elements: 209136
N. of DOFs: 129366

Santa Maria delle Grazie
18th c., Tremestieri Etneo (CT)

Bell tower dimensions:
h = 16.8 m h' = 12.6 m
b = 3.15x3.35 m
h'/b=4.0



N. of Nodes: 6071
N. of Elements: 23963
N. of DOFs: 18375

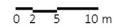


Figure 121. Finite element models of the analysed towers obtained through discretisation with tetrahedral solid elements.

certainties therefore concern the mechanical properties of the masonry, particularly the elasticity modulus, Poisson's ratio and specific weight. To investigate the sensitivity of the results to these parameters, different values of elasticity modulus were assigned to the material during the eigenvalue modal analyses (Table 17). These values were selected within the ranges commonly reported in the literature for historical masonry (Liberatore, 2000; Ministero delle Infrastrutture e dei Trasporti, 2018). As regards the self-weight of the masonry, a specific weight of $\gamma = 20 \text{ kN/m}^3$ was adopted in the analysis of all the towers, corresponding to a typical value for the masonry characterising the towers under study. It should be noted that, for the limited range of variability plausibly attributable to the masonry considered, of the order of 10-20%, the resulting variability in the frequencies would remain below 4-8% (Li Rosi, 2024).

The results of the modal analyses provided preliminary information on the dynamic behaviour of the towers, allowing the identification of the fundamental vibration modes and their associated frequencies, which represent a key parameter in the assessment of the seismic behaviour of slender masonry structures (Figure 122). This preliminary modelling phase represents an essential step for the future calibration of the structural models through experimental measurements, such as dynamic identification tests, which are widely used to identify the modal parameters of historic masonry towers. The integration of accurate geometric documentation and numerical structural modelling therefore constitutes a fundamental tool for understanding the structural behaviour of historic towers and for supporting future strategies aimed at their conservation and risk mitigation.

Table 17. Modal frequencies of the first three vibration modes of the analysed towers obtained through eigenvalue modal analysis in Midas FEA NX. Percentage in brackets are referred to the $E=500 \text{ MPa}$ basic value.

	s [m]	n [-]	γ [kN/m ³]	M [kg]	E [MPa]	f_1 [Hz]	f_2 [Hz]	f_3 [Hz]
Pedara S. Caterina	1.20	0.25	20000	1'709'835	500	0.54	0.55	2.09
					2000 (+300%)	1.09 (+100%)	1.10 (+100%)	4.18 (+100%)
					4000 (+700%)	1.54 (+183%)	1.55 (+183%)	5.91 (+183%)
Acireale Ss. Ann. (north)	1.1-0.6	0.25	20000	1'126'440	500	0.88	0.91	2.34
					2000 (+300%)	1.76 (+100%)	1.81 (+99%)	4.69 (+100%)
					4000 (+700%)	2.49 (+183%)	2.56 (+182%)	6.64 (+184%)
Acireale Ss. Ann. (south)	1-0.6	0.25	20000	1'033'040	500	0.83	0.88	2.16
					2000 (+300%)	1.65 (+100%)	1.76 (+99%)	4.32 (+100%)
					4000 (+700%)	2.33 (+182%)	2.50 (+183%)	6.11 (+183%)
Adrano S. Pietro	1.70	0.25	20000	1'747'030	500	0.823	0.803	2.65
					2000 (+300%)	1.65 (+100%)	1.61 (+100%)	5.29 (+100%)
					4000 (+700%)	2.33 (+183%)	2.27 (+183%)	7.49 (+182%)
Tremestieri S. Maria Grazie	0.65- 0.70	0.25	20000	183'441	500	1.59	1.64	5.14
					2000 (+300%)	3.19 (+100%)	3.28 (+100%)	10.29 (+100%)
					4000 (+700%)	4.51 (+183%)	4.64 (+183%)	14.55 (+183%)

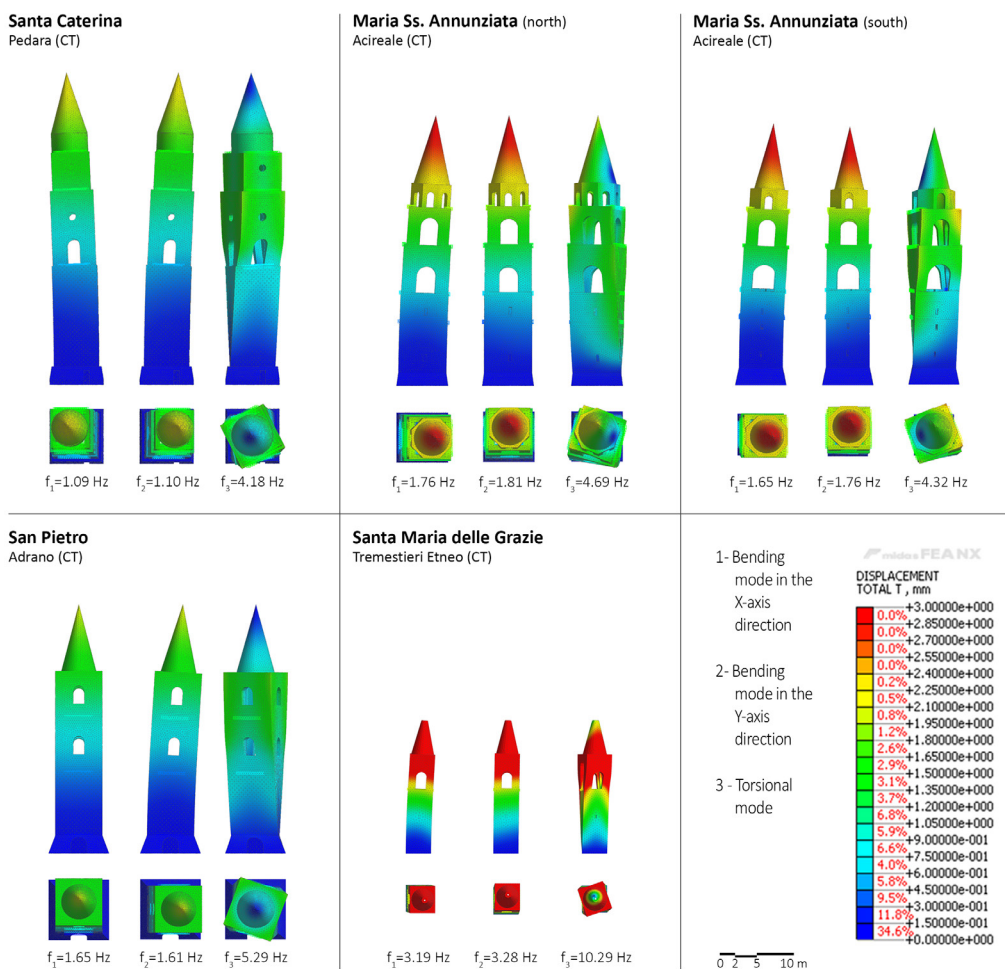


Figure 122. Modal shapes of the first three vibration modes obtained through eigenvalue modal analysis.

The analysis of modal shapes has contributed to understanding whether the bell tower spires are involved in the deformation process of the structure or whether they are simply carried along by the structure's motion, undergoing only rigid motions. As can be seen in Figure 122, the displacement field at the spires is characterised by nearly constant translation values along the height of the spire itself, especially in the San Pietro and Santa Maria delle Grazie towers, indicating that, since the variations in displacement are negligible, the spire undergoes the displacement of the tower head without undergoing significant deformation.

It follows that the failure of the roofs of the towers under investigation may result from the overturning of the entire upper section, but less likely from cracking of its surface.

These conclusions are confirmed by historical findings that highlight the presence of cracking patterns not caused by seismic events, but rather by other causes of deterioration, such as rainwater infiltration or wind action.



Chapter 9 - Survey for the Preliminary Documentation of the Restoration of the Escuelas Pías Dome in Valencia: Analysis and Methodological Comparison

Within the broader context of architectural roof coverings clad with ceramic tiles, the domes of the Valencian tradition represent one of the most significant examples of integration between masonry structures and glazed ceramic coverings. Among these, the dome of the Escuelas Pías church in Valencia represents a particularly relevant case study, both for its architectural characteristics and for the conservation issues that have required restoration (Figure 123).

As part of the preliminary investigations supporting the restoration project, a survey campaign was therefore conducted to document the geometry and material characteristics of the entire church complex. The survey, carried out through the integration of digital acquisition techniques, made it possible to obtain an accurate representation of the geometry of the building and its main architectural components, while also providing detailed documentation of crack patterns and structural deformations. These outputs constitute a fundamental knowledge base for the subsequent phases of analysis and for the definition of restoration interventions.

The analysis of this case study also allows a comparison between the survey methods adopted for documenting a ceramic-clad dome and those employed, during the present research, for the study of spires made of glazed ceramic bricks widespread in the Sicilian context. Although these architectural typologies differ in terms of geometry, construction system and configuration of the ceramic covering, both present similar issues related to the documentation of complex surfaces characterised by modular glazed ceramic elements. The comparison between the two cases therefore makes it possible to highlight similarities and differences in data acquisition and documentation strategies, contributing to a methodological reflection on survey techniques applied to architectural ceramic roof coverings.

This chapter therefore examines the dome of the Escuelas Pías in Valencia, with particular attention to its architectural and constructive characteristics, the integrated digital survey methodologies adopted, and the role of geometric documentation in supporting restoration activities. The final part of the chapter also presents a methodolog-

◀ Detail of the dome of the Escuelas Pías in Valencia.



Figure 123. Escuelas Pías complex.

ical comparison between the survey of this type of roof and that of the Sicilian spires analysed in the previous chapters, in order to highlight similarities and differences in acquisition and documentation strategies.

9.1 - The Dome of the Escuelas Pías in Valencia

The church of the Escuelas Pías, dedicated to Saint Joachim, is located in the historic centre of Valencia, in the Velluters district, within the educational complex founded by the Piarist order. The educational institution was introduced into the city in the first half of the eighteenth century, and the college was built between 1739 and 1747. Construction of the church began in 1767, based on the design of the *maestro de obras* José Puchol and promoted by the archbishop Andrés Mayoral. Because of financial difficulties and the death of the archbishop, the works underwent several modifications and delays; however, the building was completed towards the end of the eighteenth century and consecrated in 1773 (Cortés-Meseguer, in press; Rodríguez-Navarro & Gil-Piqueras, 2020).

From a compositional perspective, the church presents a centralised layout organised around a circular space, a solution that differs from the typical tradition of Valencian ecclesiastical architecture of the period. The main hall is defined by a system of ten massive buttresses that subdivide the plan into ten radial sectors and support the large dome covering the entire interior space. Chapels and passageways open between the buttresses, while the main entrance connects directly with the street and a secondary access links the church to the cloister of the college. The architectural complex occupies an entire urban block and is composed of the main façade, the bell tower and the college buildings (Rodríguez-Navarro & Gil-Piqueras, 2020).

The dominant element of the composition is the large hemispherical dome, which represents one of the most significant structures of Valencian Neoclassical architecture. With an internal span of approximately 24.5 m, the dome is articulated into ten struc-



Figure 124. Urban context of the Escuelas Pías church in the historic centre of Valencia. Below, views of the dome.

tural sectors corresponding to the radial subdivision of the hall below. The spatial and compositional solution recalls models of classical architecture, and particularly the organisation of large centrally planned domes, highlighting references to the tradition of monumental domed architecture within European culture (Cortés-Meseguer, in press; Soler-Estrela et al., 2022). Externally, the dome shell is clad with blue glazed ceramic tiles, according to a tradition widely diffused in the Valencian region, where blue ceramic roof coverings constitute one of the most characteristic elements of the urban landscape and of religious architecture. Owing to its ceramic covering and its dimensions, the dome is clearly visible in the skyline of the Velluters district and represents one of the most recognisable architectural elements in the urban skyline (Figure 124).

The interior layout of the building develops through a series of vertically arranged levels (Figure 125). At the lower level are the chapels and the main access points, while



Figure 125. Interior of the Escuelas Pías church.

the second level is characterised by spaces between the buttresses and by a gallery overlooking the central hall. Above the upper cornice are niches containing statues of the apostles and a series of openings that allow natural light to illuminate the space below. The uppermost level consists of the dome shell, which dominates the entire architectural structure and defines the external image of the building within the urban landscape of the city (Rodríguez-Navarro & Gil-Piqueras, 2020).

Within the context of eighteenth-century Valencian architecture, the church of the Escuelas Pías therefore constitutes a particularly important case because of the dimensions of its dome and the compositional solution adopted, which combines a centralised plan with a structure articulated by radial buttresses. The geometric and constructive complexity of the roof structure, together with the presence of the glazed ceramic covering, made it necessary to undertake an extensive documentation campaign as part of the preliminary studies for the recent restoration intervention, which forms the subject of the analyses presented in the following sections.

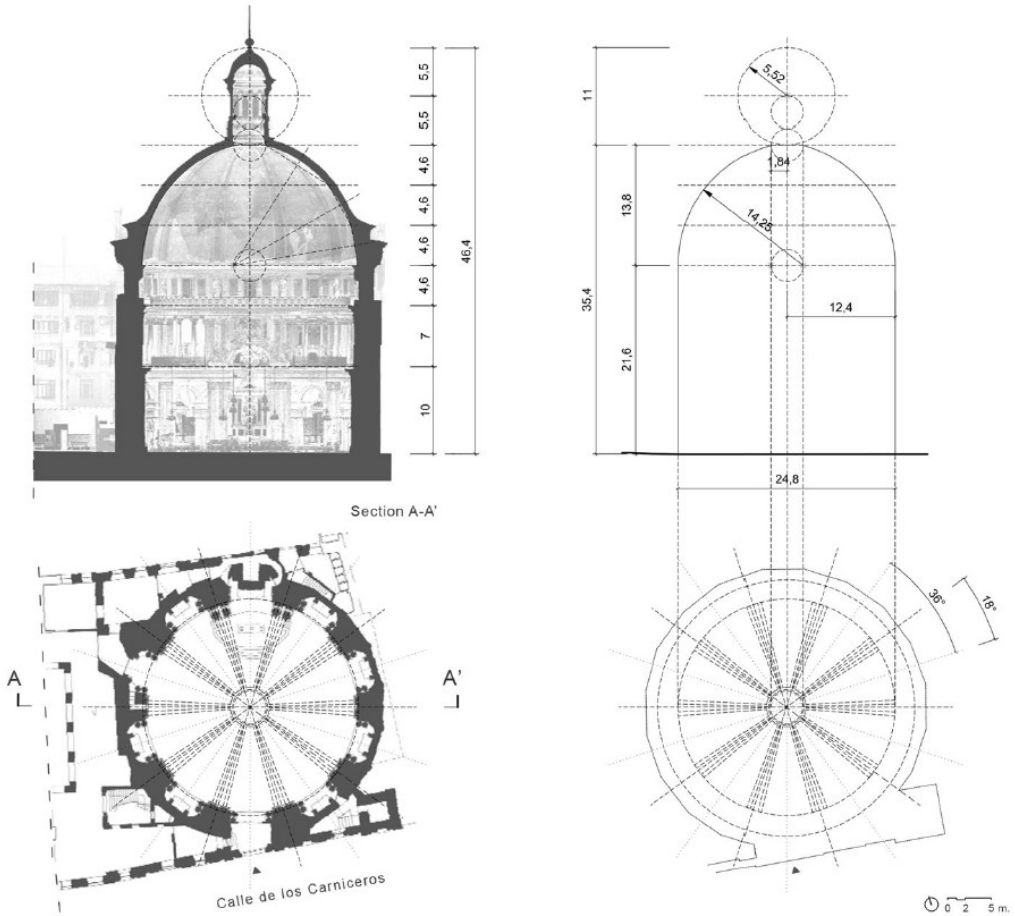


Figure 126. Plan and section of the Escuelas Pías church with the geometric scheme of the dome.

9.2 - Construction System and Material Characteristics of the Dome

The dome of the Escuelas Pías church is the main architectural feature of the building and constitutes one of the most significant structures of eighteenth-century Valencian architecture. It is a masonry dome set on a drum articulated by ten buttresses that subdivide the interior space into an equal number of radial sectors and define the structural organisation of the hall (Cortés-Meseguer, in press) (Figure 126).

The construction of the building is mainly based on the use of three fundamental materials: brick, lime and gypsum. Bricks constitute the principal material used for the construction of the dome and of the horizontal structural elements, while lime is employed as the binder in the masonry and surface coatings. Gypsum is used mainly in finishing layers and interior plasters. In some parts of the structure, stone elements and metal ties are also present, used as stiffening components of the masonry (Cortés-Meseguer, in press).



Figure 127. Detail of the ceramic tile cladding of the Escuelas Pías dome.

From a construction perspective, the dome is built in brick masonry with a thickness of approximately 48 cm, even though the internal span reaches about 24.5 m. The structure is supported by relieving arches positioned above the openings of the drum and continues with masonry that becomes progressively lighter towards the top. In the lower part, larger bricks are used (approximately $48 \times 24 \times 5$ cm), while in the upper levels smaller elements are employed (approximately $30 \times 15 \times 4$ cm), a solution that allows the weight of the structure to be reduced during the development of the dome shell (Cortés-Meseguer, in press).

A particularly interesting aspect concerns the geometric configuration of the dome. Despite the relatively limited thickness of the masonry, the structure is able to span a very large space thanks to the shape of the dome shell and to the adopted construction system. The dome presents a slightly different geometry between the interior and the exterior: internally the curvature is more pronounced, while externally it assumes a flatter profile. This difference is related to the presence of a masonry pier (*machón*) at the base of the structure, which stiffens the drum and helps support the springing of the dome. The masonry is also reinforced by the presence of three metal rings positioned at different heights along the dome, inserted to counteract the horizontal thrusts generated by the geometry of the structure (Cortés-Meseguer, in press).

Externally, the roof covering is protected by a cladding composed of ceramic tiles of the *teja árabe* type, laid according to the traditional pan-and-cover tile system. In this system the concave elements (channels) are placed directly on the surface of the dome shell, while the convex elements (cover tiles) remain visible externally and constitute the protective layer of the roof covering. In the case of the Escuelas Pías dome, the cover tiles are glazed in blue, while the channel tiles remain uncoated. The external surface of the dome is also articulated by ribs corresponding to the radial subdivision of the ten structural sectors. Externally, these elements are emphasised by two rows of white glazed tiles, which mark the junction lines between the different sectors of the dome shell and contribute to reinforcing the geometric reading of the dome (Soler-Estrela et

al., 2022) (Figure 127).

At the top of the dome shell stands the lantern, also clad with blue and white glazed ceramic tiles, which completes the composition of the roof and contributes to defining the architectural image of the dome within the urban skyline of the city.

9.3 - Survey and Documentation as a Preliminary Knowledge Phase for Restoration

In recent decades, the dome of the Escuelas Pías church has been the subject of several studies aimed at understanding its structural behaviour and documenting the construction characteristics of the building. In this context, the architectural survey has played a fundamental role as a tool for investigating the structure, making it possible to acquire accurate information on its geometric configuration, the constructive organisation of the masonry, and the crack pattern and visible deterioration phenomena. The documentation produced concerned the entire architectural complex of the church and constituted an essential knowledge base for subsequent structural analyses and for the definition of restoration interventions (Rodríguez-Navarro & Gil-Piqueras, 2020; Soler-Estrela et al., 2022).

Earlier studies had already produced graphic documentation of the dome through a survey carried out by means of point measurements supported by topographic instruments. The result was a geometrically accurate vector representation describing the



Figure 128. Data acquisition using the terrestrial laser scanner ScanStation P40.

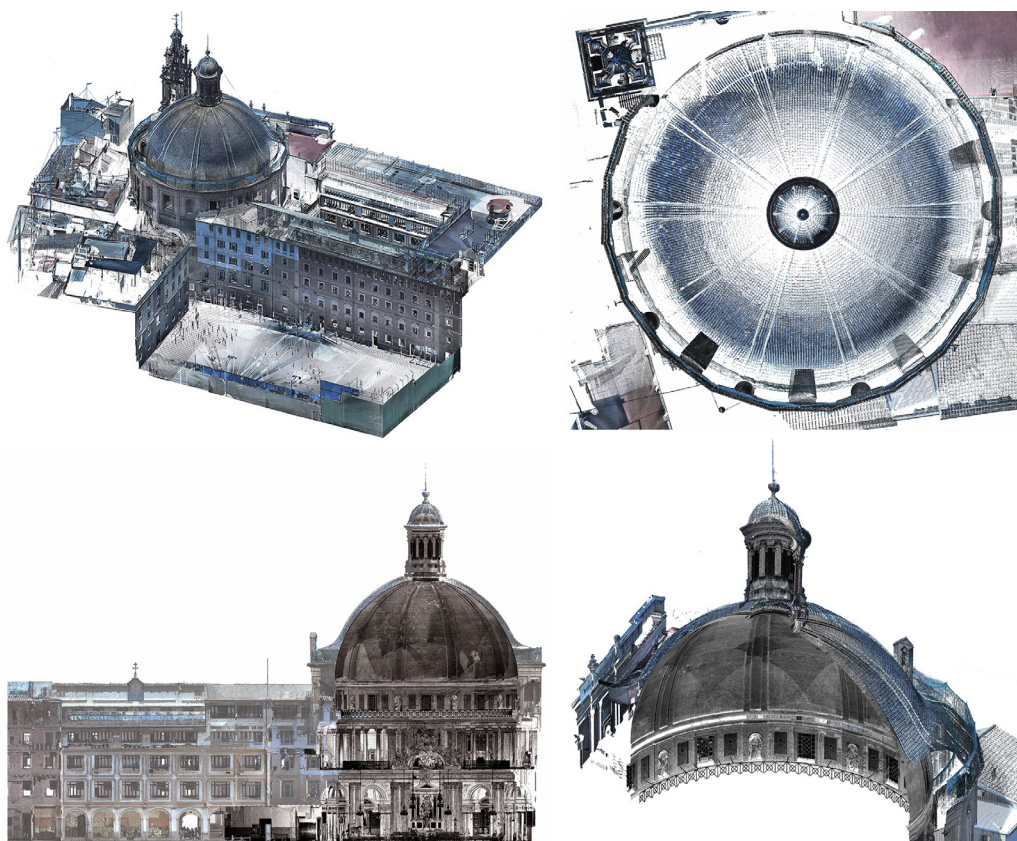


Figure 129. Point cloud obtained from the processing of the laser scans.

general configuration of the building. However, this representation was based on a simplified model of the dome and did not allow the precise detection of structural deformations or damage phenomena developed over time (Rodríguez-Navarro & Gil-Piqueras, 2020).

To overcome these limitations, more recent studies have employed high-precision digital survey techniques based on three-dimensional data acquisition. A terrestrial 3D laser scanning (TLS) system was used, employing a Leica ScanStation P40 scanner capable of acquiring up to one million points per second and capturing RGB colour information for each measured point (Figure 128). In total, 54 scans were performed, distributed both inside and outside the building, to ensure complete coverage of the structure and sufficient overlap between the different acquisitions. The registration of the individual point clouds made it possible to obtain a complete three-dimensional model of the dome and the surrounding parts of the building (Rodríguez-Navarro & Gil-Piqueras, 2020) (Figure 129).

The laser scanning survey was integrated with a photogrammetric survey based on Structure from Motion (SfM) techniques, aimed at the three-dimensional reconstruction of the church surface. The images were acquired using a Sony α 7R camera with a resolu-



Figure 130. Three-dimensional model obtained through photogrammetry.

tion of 36.4 megapixels, organised into two circular image sequences and subsequently processed using Agisoft Metashape software to generate a textured three-dimensional model. This model made it possible to analyse more precisely the chromatic variations and surface discontinuities of the masonry, making the distribution of cracks and areas of deterioration on the dome shell more evident (Rodríguez-Navarro & Gil-Piqueras, 2020) (Figure 130).

9.4 - Restoration Interventions

Before the most recent restoration works, the dome of the Escuelas Pías church exhibited a widespread state of deterioration affecting both the roof covering system as a whole and the individual ceramic elements forming the cladding of the dome shell. The conservation conditions of the roof had progressively compromised the effectiveness of the waterproofing system, favouring rainwater infiltration and deterioration processes affecting both the tiles and the underlying structures. During the preliminary investigations carried out prior to the restoration, it therefore became necessary to systematically analyse the different forms of deterioration affecting the roof. To this end, a classification of the pathologies was adopted that distinguishes between phenomena affecting the construction system of the roof as a whole and those directly concerning the ceramic tiles. This distinction makes it possible to separate problems related to the behaviour of the construction system from those connected to the material characteristics and durability of the ceramic elements (Cortés-Meseguer, in press).

The deterioration phenomena affecting the roof covering system as a whole include the following:

- Errors in the layout and construction of the roof covering (Figure 131a);



Figure 131. Examples of the main pathologies observed in the roof covering system of the Escuelas Pías church.

- Insufficient overlap between the tiles (Figure 131b);
- Disintegration, detachment and loss of mortar in the joints (Figure 131c);
- Misalignment of the channel tiles of the roof covering (Figure 131d);
- Presence of through cracks and surface cracks (Figure 131e);
- Missing tiles (Figure 131f);
- Presence of incompatible elements (iron elements (Figure 131g), cement mortars, tiles of different colours);
- Presence of invasive vegetation (Figure 131h) and fauna.

By contrast, the deterioration phenomena observed directly on the tiles include the following:

- Presence of cracks and fissures in the ceramic element and in the glaze (Figure 132a);
- Glaze flaking caused by calcium oxide nodules in the ceramic body, soluble salts in the ceramic body, or exposure to fire (Figure 132b);
- Chipping caused by mechanical impact (Figure 132c);
- Chromatic alteration of the glaze (Figure 132d);
- Glaze pitting (Figure 132e);
- Glaze firing defects (Figure 132f);
- Presence of surface deposits.

Within the framework of the preliminary studies for the restoration, structural analyses were also carried out in order to verify the stability of the dome. Using graphic statics procedures, the behaviour of the masonry dome shell was analysed in relation to the



Figure 132. Examples of the main pathologies observed in the tiles of the Escuelas Pías church.

main acting loads, evaluating the position of the thrust line within the thickness of the structure and the influence of existing cracks and thermal variations on the stress state of the masonry (Soler-Estrela et al., 2022).

Based on the diagnostic investigations and the analyses carried out on the roof covering, the restoration project was defined according to criteria aimed at preserving the largest possible number of original elements and maintaining the material and chromatic characteristics of the ceramic cladding (Figure 133). In particular, the intervention prioritised the recovery of the existing tiles, limiting replacement only to elements that were no longer recoverable and adopting technical solutions compatible with the origi-

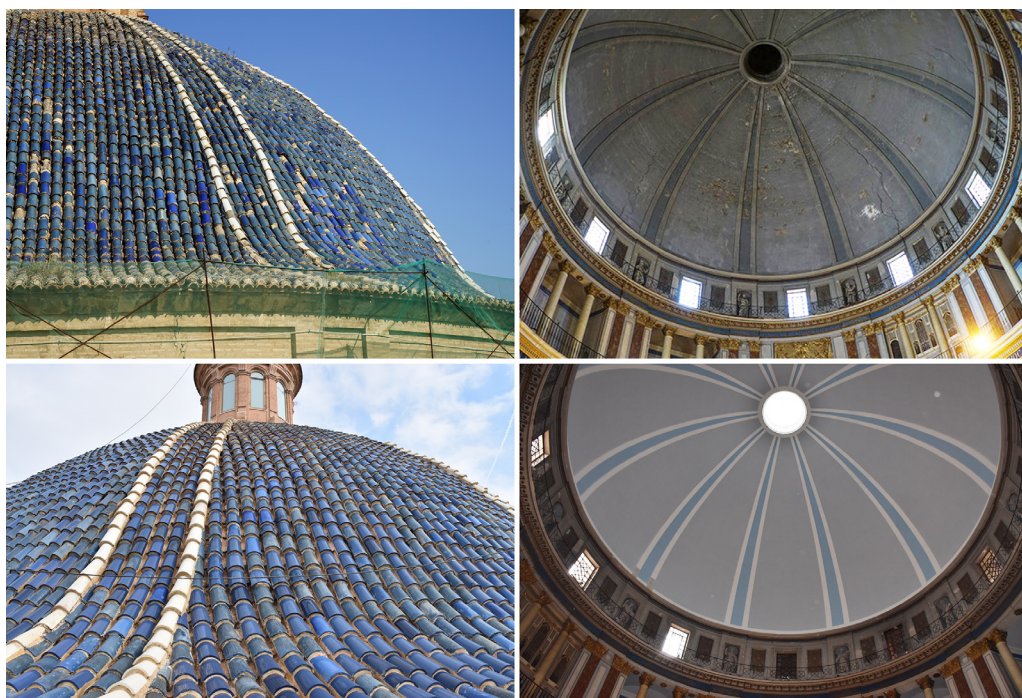


Figure 133. Dome of the Escuelas Pías before (top images) and after restoration (bottom images).

nal construction system of the roof.

Regarding the roof covering, the operations first involved the removal of damaged or unstable elements and the subsequent selection of recoverable tiles. The original tiles underwent cleaning and consolidation treatments and, where possible, restoration of the glaze through re-glazing techniques. In cases where the elements were no longer recoverable, they were replaced using reclaimed historic tiles obtained from demolition or new tiles specifically produced with material and chromatic characteristics compatible with the original ones.

The interventions also included the restoration of the joint mortars and the adjustment of the tile laying system, to re-establish the correct functioning of the roof covering and ensure improved waterproofing of the dome shell. In some areas of the roof, strengthening interventions were also carried out using materials compatible with the existing structure, aimed at improving the behaviour of the roof without altering its original construction characteristics. Maintenance and restoration operations also involved the upper lantern, with interventions aimed at improving the protection of the roof (Cortés-Meseguer, in press).

9.5 - Methodological Considerations on the Survey and Comparison with Sicilian Spires

The case study of the Escuelas Pías dome highlights the central role of the architectural survey in the processes of knowledge and conservation of historic ceramic roof coverings. The geometric and material documentation of the structure makes it possible to acquire fundamental information both on the constructive configuration of the dome and on the state of conservation of the ceramic cladding. In this sense, the survey constitutes an essential knowledge base for subsequent diagnostic and structural analyses and for the definition of intervention strategies.

In the case of the Valencian dome, the survey does not merely consist of the geometric representation of the architectural structure, but also assumes a diagnostic function, allowing the main pathologies of the roof covering and the alterations of the ceramic cladding to be identified and documented with precision. The availability of three-dimensional models and detailed surface documentation makes it possible to support the analysis and design phases, contributing to the definition of interventions aimed at preserving the original elements and maintaining the material and chromatic characteristics of the roof covering.

The analysis of this case study also provides useful insights for defining survey methodologies applicable to ceramic roof coverings. The geometric, formal and technical-constructive characteristics of these structures significantly influence the choice of documentation techniques and data acquisition strategies. Glazed ceramic roof coverings represent an important component of the architectural heritage of the Mediterranean and are widespread both in the Italian and in the Spanish context, particularly in monumental religious buildings. Within this framework, the spires of Sicilian bell towers and the domes clad with glazed tiles in the Valencian Community represent two

architectural typologies characterised by the use of ceramic materials as roof coverings, but distinguished by different geometric configurations, dimensions and construction techniques.

These differences directly affect the ways in which the survey of these structures can be approached. In the case of domes, the surfaces are generally large and continuous, characterised by relatively regular geometries and by interior spaces of considerable size. By contrast, in bell towers surmounted by spires the survey operations are often more complex due to the presence of narrow internal spaces, articulated vertical circulation paths and limited lighting conditions, factors that make the acquisition and documentation of surfaces more difficult. Moreover, the presence of glazed ceramic elements introduces additional critical issues related to the reflective nature of the material and the complexity of the surface texture, aspects that require particular attention when selecting acquisition techniques and data processing strategies. For these reasons, the documentation of such architectures requires the adoption of integrated digital survey approaches capable of combining different technologies and acquisition methodologies to accurately document the geometry of the structures, the configuration of the ceramic elements and their state of conservation (Russo et al., 2025).

From this perspective, the analysis of the Escuelas Pías dome has provided an important methodological reference for defining the survey strategies adopted in the study of the majolica-clad spires of Sicilian bell towers investigated in the present research. The comparison between the two typologies has made it possible to highlight how accurate geometric and material documentation represents a fundamental tool for understanding these architectures and for defining restoration interventions that are both targeted and compatible with the specific construction characteristics of historic ceramic roof coverings.



Chapter 10 - Conclusions and Future Developments

This research has addressed the topic of towers with glazed ceramic coverings in Sicily, with particular reference to spires made of wedge-shaped bricks, through a multi-scale approach that relates the architectural dimension of the individual artefact to its territorial and production context. The adopted framework integrates typological analysis, the study of materials and construction techniques, territorial investigations, and digital tools for data documentation and management. This has made it possible to construct a structured body of knowledge and to propose an operational model oriented towards the conservation and enhancement of these artefacts. As summarised in the methodological diagram (Figure 1), the adopted methodology is structured around four interconnected domains – Cataloguing Standards, Relational Modelling, Digital Survey, and Territorial Analysis – through which the research questions were addressed in relation to the selected case studies.

The first research question addressed the identification of the morphological, material, decorative, and constructive characteristics of wedge-shaped glazed brick spires in Sicily, and investigated whether this construction technique can be recognised as a structured territorial specificity. This question was addressed through the Cataloguing Standards, Relational Modelling, and Territorial Analysis domains of the methodology.

The study defines a coherent typological framework, characterised by recurring geometric configurations, laying techniques, and polychrome decorative schemes. These artefacts emerge not as isolated cases, but as a widespread and recognisable phenomenon. A key outcome concerns their strong relationship with the territorial context: based on the current state of knowledge, no comparable developments have been documented outside Sicily. In other Italian contexts, similar structures are generally realised with shaped brick elements left exposed and lacking glazed finishes, while glazed examples remain sporadic and not associated with a consolidated tradition. This supports the interpretation of glazed wedge-shaped brick spires as the expression of a specifically Sicilian technical knowledge and material culture, closely linked to ceramic production centres and the availability of local resources.

◀ Detail of the spire of San Pietro in Adrano (CT).

The second research question explored the relationships between spires, towers, ceramic production centres, quarries, and the territorial context, with the aim of identifying possible correlations between geographical proximity, production systems, and the spatial and temporal diffusion of the phenomenon. This question was addressed through the Relational Modelling and Territorial Analysis domains of the methodology.

The integration of a relational database and a GIS environment enables the interpretation of these relationships within a structured territorial system. The results indicate a significant correlation between the distribution of spires and their proximity to major production centres, suggesting that geographical, economic, and production-related factors play a determining role in shaping the phenomenon. Although the provenance of materials cannot always be established with certainty, spatial analysis allows recurring patterns to be identified and provides a first interpretative framework for understanding distribution dynamics.

The third research question examined the contribution of digital survey to the documentation, knowledge, and conservation of ceramic spires. This question was addressed through the Cataloguing Standards and Digital Survey domains of the methodology.

Digital survey proves to be a fundamental tool for the investigation of these complex architectural forms. The integration of terrestrial and mobile laser scanning with UAV-based photogrammetry enables the generation of high-resolution geometric models, from which two-dimensional and three-dimensional outputs can be derived for both architectural analysis and diagnostic and structural applications. The application of the protocol to the selected case studies confirms its operational effectiveness and highlights, through comparison between different towers, specific aspects related to accessibility conditions, geometric configurations, and construction characteristics of the spires. The developed workflow can therefore be considered a reliable tool for the systematic documentation of spires, even in contexts characterised by high complexity and limited accessibility.

The fourth research question investigated the replicability of the proposed methodological model, assessing whether it can be applied to other territorial contexts or to different types of architectural artefacts. This question was addressed through the integration of the Relational Modelling, Territorial Analysis, and Digital Survey domains of the methodology.

The proposed methodological model demonstrates a good degree of transferability, thanks to the integration of digital survey, territorial information systems, and analytical tools. The comparative reflection developed through the case of the dome of the Escuelas Pías in Valencia, although limited to survey and documentation phases, highlights the flexibility of the workflow and its capacity to adapt to different architectural typologies while respecting their specific constructive and material characteristics.

Alongside the achieved results, the research presents some limitations. Difficulties in accessing many of the analysed structures have affected both the survey methodology and the level of detail achieved, particularly about the internal parts of the spires. In addition, the limited availability of documentary sources has made historical reconstruction and, in some cases, the identification of production chains more complex. These

issues indicate the need for further investigation, both from a documentary and an analytical perspective.

With regard to protection and safeguarding, the research provides a structured knowledge base that can support future conservation strategies for glazed ceramic spires. By integrating cataloguing, digital survey, relational modelling, and GIS-based analysis, the proposed methodology enables the current state, material characteristics, construction features, and territorial relationships of these artefacts to be documented and interpreted. Although it does not constitute a conservation intervention in itself, it offers an operational framework for identifying priorities, supporting monitoring activities, and guiding future diagnostic or restoration actions.

The results obtained open up several potential directions for future research. Further investigation of the relationships between production centres and spires is needed in order to clarify material supply dynamics, particularly where provenance remains uncertain. Another line of development concerns the validation and extension of the database structure and the information model to other territorial contexts and architectural typologies, to test their robustness, flexibility, and interoperability. In this perspective, application to different systems, such as Valencian ceramic domes, may help to assess the adaptability of the model to contexts characterised by different construction traditions, geometric configurations, and relationships between structure and cladding. It is also relevant to define a specific cataloguing record for ceramic coverings, capable of addressing the current limitations of existing standards and of considering these elements both as constructive components and as decorative systems. Finally, the integration between geometric models and structural analysis can be further developed through advanced numerical studies aimed at investigating the behaviour of spires, for example through non-linear static and dynamic analyses under seismic or wind actions.

Overall, the research contributes to defining a coherent body of knowledge on a topic that remains relatively underexplored, proposing tools and methods for the documentation, understanding, and conservation of Sicilian ceramic spires, and opening new perspectives in the field of architectural representation and heritage management. Within this framework, the proposed integrated approach, based on the relationship between architectural scale and territorial dimension, enhances the value and recognisability of a heritage that expresses a specific material and constructive culture. At the same time, it contributes to the development of operational tools for the knowledge and management of the built environment, highlighting the role of digital technologies as instruments connecting data, interpretation, and design.

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Chapter 2

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Figure 28. On the left, photograph from "Monasterios de España" website; on the right, author's photographs.

Figure 33. On the left, author's photograph; on the right, photograph on Region of Valencia website.

Figure 34. On the left, author's photograph; on the right, photograph by Luis Cortés-Meseguer.

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Figure 126. Rodríguez-Navarro & Gil-Piqueras, 2020.

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Unless otherwise indicated, all surveys were carried out by the author under the supervision of Prof. Mariateresa Galizia, in collaboration with Prof. Graziana D'Agostino, Eng. Raissa Garozzo, and Eng. Nicoletta Campofiorito.

***Appendix - Cataloguing record of the south
bell tower of the Cathedral of Acireale***

Liv. 1	TORRE			
Liv. 2	Tipologia	di edificio o complesso religioso	Cattedrale Maria Santissima Annunziata, Acireale	
Liv. 2	Codice identificativo	torre_01		
Liv. 2	Posizionamento	rinvio a immagine con posizionamento		
Liv. 2	Sistema di torri	facente parte di un sistema a più torri	doppie	
Liv. 2	Funzione	campanaria dell'orologio		
Liv. 2	POSIZIONE			
Liv. 3	Torre isolata	no		
Liv. 3	TORRE NON ISOLATA			
Liv. 4	Specifiche	attigua/addossata ad altri edifici	parzialmente	
Liv. 4	Ulteriori specifiche	in posizione decentrata (rispetto alla parte di riferimento)		
Liv. 4	Edificio / complesso di riferimento	architettura religiosa	chiesa / oratorio	in facciata
Liv. 4	Quota	complanare		
Liv. 4	Sporgenza	non sporgente		
Liv. 4	Altezza	oltrepassata		
Liv. 4	Accesso	dal vano		
Liv. 2	Sviluppo in altezza	sviluppo variato	con snellimento	
Liv. 2	Rapporti proporzionali	rapporti proporzionali della torre rapporti proporzionali della copertura rapporti proporzionali tra la copertura e la torre	maggiori di 1:5 minori di 1:3 minori di 1:3	
Liv. 2	Discontinuità tra le parti	costruttive costruttive	all'interno della canna fra canna e cella	
Liv. 2	ELEMENTI COSTITUTIVI			
Liv. 3	Definizione	basamento		
Liv. 3	Codice identificativo	elem_cost_01		
Liv. 3	Rapporto con il terreno	fuori terra		
Liv. 3	Configurazione	chiuso - cieco		
Liv. 3	Volume	pieno		
Liv. 3	Numero di piani / livelli	altro		0
Liv. 3	SVILUPPO IN PIANTA			
Liv. 4	Geometria del perimetro esterno	quadrangolare	quadrata	
Liv. 3	MATERIALI E TECNICHE			
Liv. 4	Tipo di elemento	basamento		
Liv. 4	Materiali	pietra lavica malta		
Liv. 4	Tecniche	muratura pseudoisodoma		
Liv. 4	Finiture	faccia a vista		
Liv. 3	Numero di registri in alzato	un registro		
Liv. 3	DETTAGLI SVILUPPO IN ALZATO			
Liv. 4	Articolazione del vano e delle pareti	cieca		
Liv. 4	Descrizione	Basamento realizzato in muratura di pietra lavica a vista, costituita da conci squadrati di dimensioni non uniformi, disposti in filari orizzontali complessivamente regolari e riconducibili a una apparecchiatura pseudoisodoma. Il paramento presenta giunti di malta ben visibili. Il basamento è caratterizzata da una lieve scarpa ed è delimitata inferiormente e superiormente da elementi modanati aggettanti.		
Liv. 4	Ulteriori specifiche	basamento a scarpa		
Liv. 2	ELEMENTI COSTITUTIVI			
Liv. 3	Definizione	canna	canna singola	
Liv. 3	Codice Identificativo	elem_cost_02		
Liv. 3	Rapporto con il terreno	fuori terra		
Liv. 3	Configurazione	semiaperto		
Liv. 3	Volume	cavo		
Liv. 3	Numero di piani / livelli	altro		5
Liv. 3	SVILUPPO IN PIANTA			
Liv. 4	Geometria del perimetro interno	quadrangolare	quadrata	
Liv. 4	Geometria del perimetro esterno	quadrangolare	quadrata	
Liv. 3	CANTONALE			
Liv. 4	Caratteristiche generali	discontinuo non sporgente rispetto al filo della muratura con funzione ornamentale		
Liv. 4	Aspetti costruttivi	in blocchi / in opera muraria		
Liv. 4	Configurazione	a forma di parasta	parasta angolare	

Liv. 3	Numero di registri in alzato	più registri		2
Liv. 3	MATERIALI E TECNICHE			
Liv. 4	Tipo di elemento	primo registro		
Liv. 4	Materiali	pietra lavica malta		
Liv. 4	Tecniche	muratura in pietrame irregolare		
Liv. 4	Finiture	intonaco		
Liv. 3	MATERIALI E TECNICHE			
Liv. 4	Tipo di elemento	secondo registro		
Liv. 4	Materiali	pietra lavica malta calcarenite		
Liv. 4	Tecniche	muratura in pietrame irregolare		
Liv. 4	Finiture	rivestimento in conci squadrate di calcarenite		
Liv. 3	DETTAGLI SVILUPPO IN ALZATO			
Liv. 4	Articolazione del vano e delle pareti	finestrata presenza di finestre e/o aperture presenza di cornici presenza di alette o altre modanature presenza di mensole, peducci, ecc...		
Liv. 4	Descrizione	La canna della torre è realizzata in muratura in pietra lavica costituita da elementi irregolari di dimensioni medio-piccole (circa 0,25 × 0,35 × 0,20 m), con presenza occasionale di conci squadrate, allettati con malta di calce e azolo. Lo spessore murario è di circa 1 m. Il paramento è articolato in due registri distinti per trattamento superficiale e caratteri compositivi. Il primo registro presenta una finitura ad intonaco, con cantonali in pietra lavica squadrate. Sul prospetto principale si aprono tre finestre con cornice. Sui prospetti sono presenti elementi metallici riconducibili a chiavi di catena con configurazione a Y (due sui prospetti ovest e sud e uno sul prospetto est). Il registro è concluso superiormente da una fascia marcapiano modanata in pietra lavica, che segna il passaggio al livello superiore. Sul prospetto sud è inoltre presente il quadrante dell'orologio. Il secondo registro è caratterizzato da un rivestimento in lastre di calcarenite tenera e dalla presenza, per circa un terzo dell'altezza, di cantonali in pietra lavica squadrate. Su tre lati si aprono bifore modanate in calcarenite, mentre sul lato addossato alla chiesa è riconoscibile una bifora tamponata. All'altezza dell'imposta degli archi corre una fascia modanata continua in calcarenite. Sono inoltre presenti elementi metallici riconducibili a chiavi di catena, in numero di due per ciascun prospetto. Il registro è concluso superiormente da una fascia modanata con mensole aggettanti.		
Liv. 2	ELEMENTI COSTITUTIVI			
Liv. 3	Parte	cella		cella singola
Liv. 3	Codice identificativo	elem_cost_03		
Liv. 3	Rapporto con il terreno	fuori terra		
Liv. 3	Configurazione	aperto		
Liv. 3	Volume	cavo		
Liv. 3	Numero di piani / livelli			2
Liv. 3	SVILUPPO IN PIANTA			
Liv. 4	Geometria del perimetro interno	quadrangolare		quadrata
Liv. 4	Geometria del perimetro esterno	quadrangolare		quadrata
Liv. 3	CANTONALE			
Liv. 4	Caratteristiche generali	continuo non sporgente rispetto al filo della muratura con funzione ornamentale		
Liv. 4	Aspetti costruttivi	in blocchi / in opera muraria		a pettine irregolare
Liv. 4	Configurazione	a forma di parasta		parasta angolare
Liv. 3	Numero di registri in alzato	un registro		
Liv. 3	MATERIALI E TECNICHE			
Liv. 4	Tipo di elemento	cella		
Liv. 4	Materiali	pietra lavica		

		malta		
		calcarenite		
	Liv. 4	Tecniche	muratura in pietrame irregolare	
	Liv. 4	Finiture	rivestimento in conci squadrate di calcarenite	
Liv. 3		DETTAGLI SVILUPPO IN ALZATO		
	Liv. 4	Articolazione del vano e delle pareti	finestrata presenza di finestre e/o aperture presenza di cornici presenza di alette o altre modanature presenza di mensole, peducci, ecc...	
	Liv. 4	Descrizione	La cella campanaria è costituita da un unico registro ed è realizzata in muratura in pietra lavica costituita da elementi irregolari di dimensioni medio-piccole, con presenza occasionale di conci squadrate, allettati con malta di calce e azolo. Il paramento è caratterizzato da un rivestimento in conci di calcarenite a vista, con cantonali realizzati mediante alternanza di elementi in pietra lavica e calcarenite. Il paramento presenta uno spessore di circa 60 cm, evidenziando una riduzione rispetto alla canna sottostante. Su ciascun lato si aprono bifore con cornici modanate e decorate. All'altezza dell'imposta degli archi è presente una fascia aggettante modanata in calcarenite. Superiormente, la cella è conclusa da una fascia modanata aggettante con mensole, realizzata mediante alternanza di elementi in pietra lavica e calcarenite, che definisce il coronamento del volume.	
Liv. 2		ELEMENTI SIGNIFICATIVI		
	Liv. 3	Riferimento - definizione	basamento	
	Liv. 3	Riferimento - codice	elem_cost_01	
	Liv. 3	Posizionamento	rinvio a immagine con posizionamento	
	Liv. 3	Definizione	alette o altre modanature	modanate
	Liv. 3	Descrizione	Fasce modanate in conci di pietra lavica	
Liv. 2		ELEMENTI SIGNIFICATIVI		
	Liv. 3	Riferimento - definizione	canna	
	Liv. 3	Riferimento - codice	elem_cost_02	
	Liv. 3	Posizionamento	rinvio a immagine con posizionamento	
	Liv. 3	Definizione	cornici	modanate
	Liv. 3	Descrizione	due cornici di finestra in conci di pietra lavica squadrate; una cornice di finestra in calcarenite squadrate; tre cornici modanate in calcarenite delle bifore	
	Liv. 3	Posizionamento	rinvio a immagine con posizionamento	
	Liv. 3	Definizione	alette o altre modanature	modanate
	Liv. 3	Descrizione	Fascia marcapiano in conci di pietra lavica squadrate; modanatura in conci di calcarenite squadrate	
	Liv. 3	Posizionamento	rinvio a immagine con posizionamento	
	Liv. 3	Definizione	mensole, peducci, ecc...	modanate
	Liv. 3	Descrizione	mensole modanate in conci di calcarenite;peducci modanati in calcarenite all'imposta degli archi delle bifore	
Liv. 2		ELEMENTI SIGNIFICATIVI		
	Liv. 3	Riferimento - definizione	cella	
	Liv. 3	Riferimento - codice	elem_cost_03	
	Liv. 3	Posizionamento	rinvio a immagine con posizionamento	
	Liv. 3	Definizione	cornici	modanate
	Liv. 3	Descrizione	quattro cornici modanate nelle bifore	
	Liv. 3	Posizionamento	rinvio a immagine con posizionamento	
	Liv. 3	Definizione	alette o altre modanature	modanate
	Liv. 3	Descrizione	modanatura in conci di calcarenite squadrate	
	Liv. 3	Posizionamento	rinvio a immagine con posizionamento	
	Liv. 3	Definizione	mensole, peducci, ecc...	modanate
	Liv. 3	Descrizione	mensole modanate in conci di calcarenite e pietra lavica squadrate;peducci modanati in calcarenite all'imposta degli archi delle bifore	
Liv. 2		SISTEMI DI ORIZZONTAMENTO		
	Liv. 3	Riferimento - definizione	basamento	
	Liv. 3	Riferimento - codice	elem_cost_01	

Liv. 3	Tipo di struttura orizzontale	chiusura orizzontale di base		
Liv. 3	CHIUSURA ORIZZONTALE DI BASE			
Liv. 4	Codice identificativo	orizz_01		
Liv. 4	Rapporto con il suolo	non rilevato		
Liv. 4	Posizionamento	rinvio a immagine con posizionamento		
Liv. 4	Materiali	non rilevato		
Liv. 4	tecniche	non rilevato		
Liv. 4	Finiture	non rilevato		
Liv. 2	SISTEMI DI ORIZZONTAMENTO			
Liv. 3	Riferimento - definizione	canna		
Liv. 3	Riferimento - codice	elem_cost_02		
Liv. 3	Tipo di struttura orizzontale	porzione di cupola		
Liv. 3	CUPOLA/PORZIONE DI CUPOLA			
Liv. 4	Codice identificativo	orizz_02		
Liv. 4	Numero di cupole		1	
Liv. 4	Posizionamento	rinvio a immagine con posizionamento		
Liv. 4	Pianta	porzione delle figure sopracitate		
Liv. 4	Sviluppo esterno	non estradossata		circolare
Liv. 4	Sistema di imposta	su muri		
Liv. 4	Numero di calotte	calotta singola		
Liv. 4	Geometria in alzato della calotta	emisferica		
Liv. 4	Nervature della calotta	non nervata		
Liv. 4	Presenza del tamburo	no		
Liv. 4	Presenza del tiburio	no		
Liv. 4	Sistema di copertura	no		
Liv. 4	Materiali	non rilevato		
Liv. 4	Tecniche	non rilevato		
Liv. 4	Finiture	intonaco		
Liv. 3	Tipo di struttura orizzontale	volta		
Liv. 3	VOLTA/PORZIONE DI VOLTA			
Liv. 4	Codice identificativo	orizz_03		
Liv. 4	Numero di volte		1	
Liv. 4	Posizionamento	rinvio a immagine con posizionamento		
Liv. 4	Pianta	quadrangolare		rettangolare
Liv. 4	Sviluppo esterno	non estradossata		
Liv. 4	Nervature/costolonature	volta non nervata		
Liv. 4	Geometria	a botte		
Liv. 4	Sistema di imposta	su muri		
Liv. 4	Presenza del tamburo	no		
Liv. 4	Presenza del tiburio	no		
Liv. 4	Ulteriori specifiche	nessuna		
Liv. 4	Sistema di copertura	no		
Liv. 4	Materiali	conglomerato pietrame lavico minuto malta di calce		
Liv. 4	Tecniche	volta in conglomerato gettata in opera su cassaforma		
Liv. 4	Finiture	non presente		
Liv. 3	Tipo di struttura orizzontale	solaio		
Liv. 3	SOLAIO			
Liv. 4	Codice identificativo	orizz_04		
Liv. 4	Numero di solai		1	
Liv. 4	Posizionamento	rinvio a immagine con posizionamento		
Liv. 4	Tecnica	a ordito e impalcato		
Liv. 4	A ordito e impalcato: orditura	a orditura semplice		
Liv. 4	A ordito e impalcato: tipo di travatura	con travatura metallica		
Liv. 4	A ordito e impalcato: elementi interpd	getto di completamento		
Liv. 4	A ordito e impalcato: tipo di alloggio d	a incastro		
Liv. 4	Sistema di copertura	no		
Liv. 4	Materiali	ferro conglomerato pietrame minuto		
Liv. 4	Tecniche	solaio a travetti metallici a doppio 'T' con riempimento in conglomerato e pietrame minuto		
Liv. 4	Finiture	non presente		
Liv. 3	Tipo di struttura orizzontale	solaio		
Liv. 3	SOLAIO			
Liv. 4	Codice identificativo	orizz_05		
Liv. 4	Numero di solai		1	

Liv. 4	Posizionamento	rinvio a immagine con posizionamento		
Liv. 4	Tecnica	a ordito e impalcato		
Liv. 4	A ordito e impalcato: orditura	a doppia orditura / con travi e travetti		
Liv. 4	A ordito e impalcato: tipo di travatura	con travatura metallica		
Liv. 4	A ordito e impalcato: elementi interposto	oggetto di completamento		
Liv. 4	A ordito e impalcato: tipo di alloggiamento	a incastro		
Liv. 4	Sistema di copertura	no		
Liv. 4	Materiali	ferro conglomerato pietrame minuto		
Liv. 4	Tecniche	solaio a travetti metallici a doppio T' con riempimento in conglomerato e pietrame minuto		
Liv. 4	Finiture	non presente		
Liv. 2	SISTEMI DI ORIZZONTAMENTO			
Liv. 3	Riferimento - definizione	cella		
Liv. 3	Riferimento - codice	elem_cost_03		
Liv. 3	Tipo di struttura orizzontale	solaio		
Liv. 3	SOLAIO			
Liv. 4	Codice identificativo	orizz_06		
Liv. 4	Numero di solai		1	
Liv. 4	Posizionamento	rinvio a immagine con posizionamento		
Liv. 4	Tecnica	a ordito e impalcato		
Liv. 4	A ordito e impalcato: orditura	a doppia orditura / con travi e travetti		
Liv. 4	A ordito e impalcato: tipo di travatura	con travatura metallica		
Liv. 4	A ordito e impalcato: elementi interposto	oggetto di completamento		
Liv. 4	A ordito e impalcato: tipo di alloggiamento	a incastro		
Liv. 4	Sistema di copertura	no		
Liv. 4	Materiali	ferro conglomerato pietrame minuto		
Liv. 4	Tecniche	solaio a travetti metallici a doppio T' con riempimento in conglomerato e pietrame minuto		
Liv. 4	Finiture	non presente		
Liv. 3	Tipo di struttura orizzontale	solaio		
Liv. 3	SOLAIO			
Liv. 4	Codice identificativo	orizz_07		
Liv. 4	Numero di solai		1	
Liv. 4	Posizionamento	rinvio a immagine con posizionamento		
Liv. 4	Tecnica	a ordito e impalcato		
Liv. 4	A ordito e impalcato: orditura	a orditura semplice		
Liv. 4	A ordito e impalcato: tipo di travatura	con travatura metallica		
Liv. 4	A ordito e impalcato: elementi interposto	oggetto di completamento		
Liv. 4	A ordito e impalcato: tipo di alloggiamento	a incastro		
Liv. 4	Sistema di copertura	no		
Liv. 4	Materiali	ferro conglomerato pietrame minuto		
Liv. 4	Tecniche	solaio a travetti metallici a doppio T' con riempimento in conglomerato e pietrame minuto		
Liv. 4	Finiture	non presente		
Liv. 3	Tipo di struttura orizzontale	tetto		
Liv. 3	TETTO			
Liv. 4	Codice identificativo	orizz_08		
Liv. 4	Numero di tetti		1	
Liv. 4	Posizionamento	rinvio a immagine con posizionamento		
Liv. 4	Tipologia generale	altri tipi		conico
Liv. 4	Aggetto	non aggettante		
Liv. 4	Orditura	altro		
Liv. 4	Elementi in muratura	intero tetto		
Liv. 4	Presenza del tamburo	si		
Liv. 4	Geometria della pianta del tamburo	poligonale		poligono equilatero
Liv. 4	Articolazione della parete in alzato del	su uno o più registri presenza di finestre e/o aperture presenza di arcate cieche o altre proiezioni di sistemi arcuati presenza di cornici presenza di mensole, peducci, ecc...		modanate modanate modanate modanate
Liv. 4	Materiali	mattoni a cuneo smaltati		

		malta		
Liv. 4	Tecniche	muratura in mattoni a due teste con mattoni posti di testa		
Liv. 4	Finiture	intonaco		
Liv. 4	Descrizione	La cuspide di forma conica è realizzata mediante una muratura a due teste in mattoni disposti di testa, in cui gli elementi a cuneo svolgono anche funzione strutturale. Presenta un diametro massimo di 4,60 m, un diametro minimo di 0,80 m e un'altezza di 6,40 m, con 111 ricorsi concentrici di mattoni. Lo spessore è pari alla lunghezza del mattone, incrementata da un sottile strato di intonaco all'intradosso, per un totale di circa 26 cm. La parte terminale è costituita da un elemento lapideo che garantisce la messa in compressione degli ultimi ricorsi e accoglie una croce con ventarola metallica, collegata agli elementi metallici esterni e all'armatura interna. La cuspide è attualmente dotata di un'intelaiatura interna metallica con funzione di armatura. La cuspide conica si imposta su un tamburo a pianta ottagonale, caratterizzato dalla presenza di otto aperture modanate, di cui tre attualmente tamponate.		
Liv. 3	Tipo di struttura orizzontale	manto di copertura		
Liv. 3	MANTO DI COPERTURA			
Liv. 4	Riferimento - definizione	tetto		
Liv. 4	Riferimento - codice	orizz_08		
Liv. 4	Ulteriori specifiche	presenza di elementi sommitali presenza di elementi scultorei e decorativi presenza di presidi tecnologici e di sicurezza		
Liv. 4	Materiali	mattoni a cuneo smaltati malta		
Liv. 4	Tecniche	muratura in mattoni a due teste con mattoni posti di testa		
Liv. 4	Finiture	non presente		
Liv. 2	PAVIMENTI			
Liv. 3	Tipo	pavimento discontinuo	a elementi	
Liv. 3	Codice identificativo	pav_01		
Liv. 3	Posizionamento	rinvio a immagine con posizionamento		
Liv. 3	MATERIALI E TECNICHE			
Liv. 4	Tipo di elemento	lastra		
Liv. 4	Materiali	marmo malta		
Liv. 4	Schema di posa	a scacchiera		
Liv. 3	SOTTOFONDO			
Liv. 4	Materiali	non rilevato		
Liv. 4	Tecniche	non rilevato		
Liv. 2	PAVIMENTI			
Liv. 3	Tipo	pavimento discontinuo	a elementi	
Liv. 3	Codice identificativo	pav_02		
Liv. 3	Posizionamento	rinvio a immagine con posizionamento		
Liv. 3	MATERIALI E TECNICHE			
Liv. 4	Tipo di elemento	piastrella		
Liv. 4	Materiali	laterizio malta		
Liv. 4	Schema di posa	a maglia quadrata		
Liv. 3	SOTTOFONDO			
Liv. 4	Materiali	non rilevato		
Liv. 4	Tecniche	non rilevato		
Liv. 2	PAVIMENTI			
Liv. 3	Tipo	pavimento discontinuo	a elementi	
Liv. 3	Codice identificativo	pav_03		
Liv. 3	Posizionamento	rinvio a immagine con posizionamento		
Liv. 3	MATERIALI E TECNICHE			
Liv. 4	Tipo di elemento	piastrella		
Liv. 4	Materiali	mattonella di cemento malta		
Liv. 4	Schema di posa	a maglia quadrata		
Liv. 3	SOTTOFONDO			

	Liv. 4	Materiali	non rilevato		
	Liv. 4	Tecniche	non rilevato		
Liv. 2		ELEMENTI STRUTTURALI AUSILIARI			
	Liv. 3	Tipologia	intelaiatura metallica costituita da cerchiate e tiranti		
	Liv. 3	Codice identificativo	elem_strutt_aus_01		
	Liv. 3	Posizionamento	rinvio a immagine con posizionamento		
	Liv. 3	MATERIALI E TECNICHE			
	Liv. 4	Tipo di elemento	intelaiatura metallica costituita da cerchiate e tiranti		
	Liv. 4	Materiali	metallo		
	Liv. 4	Tecniche			
	Liv. 4	Finitura	vernice		
Liv. 2		SCALE, RAMPE E CORDONATE			
	Liv. 3	Tipologia	scala		
	Liv. 3	Codice identificativo	coll_vert_01		
	Liv. 3	Posizionamento	rinvio a immagine con posizionamento		
	Liv. 3	Descrizione	scala interna, su rilevato massiccio in muratura, con gradini in blocchi monolitici squadrati in basalto lavico		
	Liv. 3	MATERIALI E TECNICHE			
	Liv. 4	Tipo di elemento	gradini		
	Liv. 4	Materiali	pietra lavica malta		
	Liv. 4	Tecniche	muratura in pietra		
	Liv. 4	Finiture	non presente		
Liv. 2		SCALE, RAMPE E CORDONATE			
	Liv. 3	Tipologia	scala		
	Liv. 3	Codice identificativo	coll_vert_02		
	Liv. 3	Posizionamento	rinvio a immagine con posizionamento		
	Liv. 3	Descrizione	scala interna, su rilevato massiccio in muratura, con gradini in laterizi e finitura superiore in lastre di basalto lavico		
	Liv. 3	MATERIALI E TECNICHE			
	Liv. 4	Tipo di elemento	gradini		
	Liv. 4	Materiali	laterizio malta		
	Liv. 4	Tecniche	muratura in mattoni		
	Liv. 4	Finiture	lastre di basalto lavico		
Liv. 2		SCALE, RAMPE E CORDONATE			
	Liv. 3	Tipologia	scala		
	Liv. 3	Codice identificativo	coll_vert_03		
	Liv. 3	Posizionamento	rinvio a immagine con posizionamento		
	Liv. 3	Descrizione	scala interna a rampa con travetti metallici a doppia T, riempimento in conglomerato e pietrame minuto e rivestimento dei gradini con piastrelle in cemento		
	Liv. 3	MATERIALI E TECNICHE			
	Liv. 4	Tipo di elemento	scala		
	Liv. 4	Materiali	ferro conglomerato pietrame minuto		
	Liv. 4	Tecniche	scala su struttura metallica		
	Liv. 4	Finiture	piastrelle in cemento		
	Liv. 3	MATERIALI E TECNICHE			
	Liv. 4	Tipo di elemento	parapetto		
	Liv. 4	Materiali	ferro		
	Liv. 4	Tecniche	ringhiera metallica		
	Liv. 4	Finiture	vernice		
Liv. 2		SCALE, RAMPE E CORDONATE			
	Liv. 3	Tipologia	scala		
	Liv. 3	Codice identificativo	coll_vert_04		
	Liv. 3	Posizionamento	rinvio a immagine con posizionamento		
	Liv. 3	Descrizione	scala interna in assi di legno		
	Liv. 3	MATERIALI E TECNICHE			
	Liv. 4	Tipo di elemento	gradini		
	Liv. 4	Materiali	legno		
	Liv. 4	Tecniche	scala in legno		
	Liv. 4	Finiture	non presente		
	Liv. 3	MATERIALI E TECNICHE			
	Liv. 4	Tipo di elemento	parapetto		

	Liv. 4	Materiali	legno		
	Liv. 4	Tecniche	ringhiera in legno		
	Liv. 4	Finiture	non presente		
Liv. 2		APERTURE			
	Liv. 3	Tipologia	monofora		
	Liv. 3	Numero di aperture	2		
	Liv. 3	Riferimento - definizione	canna		
	Liv. 3	Riferimento - codice	elem_cost_02		
	Liv. 3	Posizionamento	rinvio a immagine con posizionamento		
	Liv. 3	Descrizione	apertura con cornice in conci di basalto lavico, con strombatura interna svasata e avanzata in piastrelle di laterizio		
	Liv. 3	MATERIALI E TECNICHE			
	Liv. 4	Tipo di elemento	monofora		
	Liv. 4	Materiali	pietra lavica malta laterizio		
	Liv. 4	Tecniche			
	Liv. 4	Finiture	non presente		
Liv. 2		APERTURE			
	Liv. 3	Tipologia	monofora		
	Liv. 3	Numero di aperture	1		
	Liv. 3	Riferimento - definizione	canna		
	Liv. 3	Riferimento - codice	elem_cost_02		
	Liv. 3	Posizionamento	rinvio a immagine con posizionamento		
	Liv. 3	Descrizione	apertura con cornice in conci di calcarenite, con strombatura interna svasata		
	Liv. 3	MATERIALI E TECNICHE			
	Liv. 4	Tipo di elemento	monofora		
	Liv. 4	Materiali	calcarenite malta		
	Liv. 4	Tecniche			
	Liv. 4	Finiture	non presente		
Liv. 2		APERTURE			
	Liv. 3	Tipologia	bifora		
	Liv. 3	Numero di aperture	3		
	Liv. 3	Riferimento - definizione	canna		
	Liv. 3	Riferimento - codice	elem_cost_02		
	Liv. 3	Posizionamento	rinvio a immagine con posizionamento		
	Liv. 3	Descrizione	Apertura costituita da una bifora realizzata interamente in calcarenite tenera, iscritta entro un sistema di archivolti concentrici modanati impostati su piedritti articolati con colonnine addossate, che determinano un progressivo arretramento dei piani verso l'interno. L'arco esterno a tutto sesto poggia su peducci, mentre la luce è suddivisa da una colonnina centrale con capitello su cui impostano due archi gemelli a sesto acuto. Al di sopra della bifora è presente un oculo circolare. All'interno, l'apertura presenta una strombatura svasata. La soglia risulta rivestita in piastrelle.		
	Liv. 3	MATERIALI E TECNICHE			
	Liv. 4	Tipo di elemento	bifora		
	Liv. 4	Materiali	calcarenite malta		
	Liv. 4	Tecniche			
	Liv. 4	Finiture	non presente		
Liv. 2		APERTURE			
	Liv. 3	Tipologia	bifora		
	Liv. 3	Numero di aperture	4		
	Liv. 3	Riferimento - definizione	cella		
	Liv. 3	Riferimento - codice	elem_cost_03		
	Liv. 3	Posizionamento	rinvio a immagine con posizionamento		

Liv. 3	Descrizione	Apertura costituita da una bifora realizzata interamente in calcarenite tenera, inscritta entro un sistema di archivolti concentrici modanati impostati su piedritti articolati con colonnine addossate, che determinano un progressivo arretramento dei piani verso l'interno. L'arco esterno a tutto sesto poggia su peducci, mentre la luce è suddivisa da una colonnina centrale con capitello su cui impostano due archi gemelli a tutto sesto. La superficie compresa tra gli archi gemelli e l'arco maggiore è decorata con motivi floreali scolpiti. All'interno, l'apertura presenta imbotte rettilinee. La soglia è rivestita in piastrelle di cotto, in continuità con la pavimentazione interna.		
Liv. 3	MATERIALI E TECNICHE			
Liv. 4	Tipo di elemento	bifora		
Liv. 4	Materiali	calcarenite malta		
Liv. 4	Tecniche			
Liv. 4	Finiture	non presente		
Liv. 2	APERTURE			
Liv. 3	Tipologia	monofora		
Liv. 3	Numero di aperture		5	
Liv. 3	Riferimento - definizione	tetto		
Liv. 3	Riferimento - codice	orizz_08		
Liv. 3	Posizionamento	rinvio a immagine con posizionamento		
Liv. 3	Descrizione	Monofora ad arco a tutto sesto nel tamburo, realizzata in calcarenite tenera, con arco modanato impostato su piedritti semplici. In chiave è presente un elemento lapideo scolpito. L'apertura presenta imbotte rettilinee e non evidenzia strombatura. La soglia è in continuità con la pavimentazione esterna.		
Liv. 3	MATERIALI E TECNICHE			
Liv. 4	Tipo di elemento	monofora		
Liv. 4	Materiali	calcarenite malta		
Liv. 4	Tecniche			
Liv. 4	Finiture	non presente		
Liv. 2	DOCUMENTAZIONE			
Liv. 3	Riferimento - definizione	Torre sud della Cattedrale Maria Santissima Annunziata, Acireale		
Liv. 3	Riferimento - codice	torre_01		
Liv. 3	Codice rinvio documento	doc_01		
Liv. 3	Specifiche	L'Angelo custode, Antonio e Giacinto Platania, olio su tela, 1630, Cathedral of Acireale. Nel dipinto è rappresentata la città di Acireale con la Cattedrale e la sua torre sud.		
Liv. 2	DOCUMENTAZIONE			
Liv. 3	Riferimento - definizione	Torre sud della Cattedrale Maria Santissima Annunziata, Acireale		
Liv. 3	Riferimento - codice	torre_01		
Liv. 3	Codice rinvio documento	doc_02		
Liv. 3	Specifiche	Passaggio di Don Redin ad Acireale, Giacinto Platania, XVII secolo, Biblioteca e Pinacoteca Zelantea, Acireale. Nel dipinto è rappresentata la città di Acireale in cui sono evidenti la cupola della Cattedrale e la torre sud.		
Liv. 2	DOCUMENTAZIONE			
Liv. 3	Riferimento - definizione	Torre sud della Cattedrale Maria Santissima Annunziata, Acireale		
Liv. 3	Riferimento - codice	torre_01		
Liv. 3	Codice rinvio documento	doc_03		
Liv. 3	Specifiche	Veduta della città di Acireale dal mare, Emanuele Grasso, c. 1820, Biblioteca e Pinacoteca Zelantea, Acireale. Nel dipinto è rappresentata la città di Acireale in cui sono evidenti la cupola della Cattedrale e la torre sud.		
Liv. 2	DOCUMENTAZIONE			
Liv. 3	Riferimento - definizione	Torre sud della Cattedrale Maria Santissima Annunziata, Acireale		
Liv. 3	Riferimento - codice	torre_01		
Liv. 3	Codice rinvio documento	doc_04		

Liv. 3	Specifiche	Veduta della città di Acireale dal Piano dei Padri Carmelitani, Emanuele Grasso, c. 1850, Biblioteca e Pinacoteca Zelantea, Acireale. Nel dipinto è rappresentata la città di Acireale in cui sono evidenti la cupola della Cattedrale e la torre sud.		
Liv. 2	DOCUMENTAZIONE			
Liv. 3	Riferimento - definizione	Torre sud della Cattedrale Maria Santissima Annunziata, Acireale		
Liv. 3	Riferimento - codice	torre_01		
Liv. 3	Codice rinvio documento	doc_05		
Liv. 3	Specifiche	Veduta di Acireale da mare, Paul Pennisi (1930–2018), Biblioteca e Pinacoteca Zelantea, Acireale. Nel dipinto è rappresentata la città di Acireale in cui sono evidenti la cupola della Cattedrale con le sue torri con le cuspidi maiolicate.		
Liv. 2	DOCUMENTAZIONE			
Liv. 3	Riferimento - definizione	Torre sud della Cattedrale Maria Santissima Annunziata, Acireale		
Liv. 3	Riferimento - codice	torre_01		
Liv. 3	Codice rinvio documento	doc_06		
Liv. 3	Specifiche	Floristella, lettera del 9/02/1895 al Direttore dell'Ufficio Regionale per la Conservazione dei Monumenti della Sicilia a Palermo, Arch. G. Patricolo, CT 4-1 23, Archivio Soprintendenza ai beni Culturali e Ambientali di Catania.		
Liv. 2	DOCUMENTAZIONE			
Liv. 3	Riferimento - definizione	tetto		
Liv. 3	Riferimento - codice	orizz_08		
Liv. 3	Codice rinvio documento	doc_07		
Liv. 3	Specifiche	Valenti Francesco, 1903, Cattedrale di Acireale. Ispezione al campanile antico, relazione presentata all'Ufficio Regionale per la Conservazione dei Monumenti della Sicilia del Ministero della Istruzione Pubblica stesa dal Prof. Valenti, CT 4-1 25, Archivio Soprintendenza ai Beni Culturali ed Ambientali di Catania.		
Liv. 2	DOCUMENTAZIONE			
Liv. 3	Riferimento - definizione	Torre sud della Cattedrale Maria Santissima Annunziata, Acireale		
Liv. 3	Riferimento - codice	torre_01		
Liv. 3	Codice rinvio documento	doc_08		
Liv. 3	Specifiche	Valenti Francesco, 1903, Cattedrale di Acireale. Ispezione al campanile antico, relazione presentata all'Ufficio Regionale per la Conservazione dei Monumenti della Sicilia del Ministero della Istruzione Pubblica stesa dal Prof. Valenti, CT 4-1 25, Archivio Soprintendenza ai Beni Culturali ed Ambientali di Catania.		
Liv. 2	DOCUMENTAZIONE			
Liv. 3	Riferimento - definizione	Torre sud della Cattedrale Maria Santissima Annunziata, Acireale		
Liv. 3	Riferimento - codice	torre_01		
Liv. 3	Codice rinvio documento	doc_09		
Liv. 3	Specifiche	La Spina G. Vicario Generale, lettera del 23/11/1904 al Barone di Floristella, CT 4-1 41, Archivio Soprintendenza ai Beni Culturali ed Ambientali di Catania.		
Liv. 2	DOCUMENTAZIONE			
Liv. 3	Riferimento - definizione	tetto		
Liv. 3	Riferimento - codice	orizz_08		
Liv. 3	Codice rinvio documento	doc_10		
Liv. 3	Specifiche	Documenti relativi alla caduta di elementi murari dalla cuspidi nord, CT 4-1 A, 2-6-8-A, Archivio Soprintendenza ai Beni Culturali ed Ambientali di Catania.		
Liv. 2	BIBLIOGRAFIA/SITOGRAFIA			
Liv. 3	Riferimento - definizione	Torre sud della Cattedrale Maria Santissima Annunziata, Acireale		
Liv. 3	Riferimento - codice	torre_01		
Liv. 3	Codice rinvio bibliografia/sitografia	bibl_01		
Liv. 3	Specifiche	Li Rosi & Russo, 2024		
Liv. 2	BIBLIOGRAFIA/SITOGRAFIA			
Liv. 3	Riferimento - definizione	Torre sud della Cattedrale Maria Santissima Annunziata, Acireale		

Liv. 3	Riferimento - codice	torre_01		
Liv. 3	Codice rinvio bibliografia/sitografia	bibl_02		
Liv. 3	Specifiche	Donato, 1976		
Liv. 2	BIBLIOGRAFIA/SITOGRAFIA			
Liv. 3	Riferimento - definizione	Torre sud della Cattedrale Maria Santissima Annunziata, Acireale		
Liv. 3	Riferimento - codice	torre_01		
Liv. 3	Codice rinvio bibliografia/sitografia	bibl_03		
Liv. 3	Specifiche	Raciti Romeo, 1929		
Liv. 2	BIBLIOGRAFIA/SITOGRAFIA			
Liv. 3	Riferimento - definizione	Torre sud della Cattedrale Maria Santissima Annunziata, Acireale		
Liv. 3	Riferimento - codice	torre_01		
Liv. 3	Codice rinvio bibliografia/sitografia	bibl_04		
Liv. 3	Specifiche	Gravagno, 1989		
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Liv. 3	Riferimento - definizione	tetto		
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Liv. 3	Specifiche	Bella & Grasso, 2012		
Liv. 2	BIBLIOGRAFIA/SITOGRAFIA			
Liv. 3	Riferimento - definizione	Torre sud della Cattedrale Maria Santissima Annunziata, Acireale		
Liv. 3	Riferimento - codice	torre_01		
Liv. 3	Codice rinvio bibliografia/sitografia	bibl_05		
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