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Knowledge for Conservation: Architectural Archaeology for Understanding the Static Behaviour – The Case of the Brandale Tower in Savona

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Is it possible that a historical, archaeological analysis can be of great help in a study of the structural behaviour of an ancient building? How can seemingly so distant disciplines collaborate? The research on the Brandale tower involving the Department of Architecture and the Department of Engineering of the University of Genoa shows that this is not only possible but allows for clear improvements in the real understanding of the structure.The Brandale tower in Savona (Italy) is a symbol of this city. Medieval tower (1178), former seat of the municipality, is located in the historical center of Savona in a district that still retains traces of a dozen historical towers. The tower over time underwent several transformations, but the most significant was in the 16th century. Following the loss of the battle with Genoa, the tower was partially demolished. In the 20th century, thanks to the work of a few willing people, the tower was rebuilt to the height it was at the beginning of the 16th century. However, the reconstruction was carried out with very different materials and construction techniques from the original ones. Recent doubts about its stability have forced a thorough study of the tower, which is described in this article.

Introduction

The research in question, whose main contents are presented in this article, derives from ongoing work carried out by the author in recent years with the aim of adapting a discipline long used in the field of architectural restoration—namely, the archaeology of architecture—to the specific needs of structural investigation of ancient buildings for their consolidation.[1]

The article is therefore divided into two parts: a first, more theoretical section, in which the results obtained in developing a specific methodology for observation, analysis, and data recording are illustrated, particularly when the goal is to make these data useful for a structural assessment of the architecture under study (partly coinciding with a typical archaeological analysis aimed at identifying the construction phases and transformations of the structure, but partly, as will be shown below, requiring certain differences in order to optimize the study in relation to the intended objective);[2] and a second, more applied section, consisting of the illustration of a

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1. Although we conducted the research together, paragraphs 1, 2, 3, 7 were written by Daniela Pittaluga, 4,5,6 by Camilla Sbardella.

2. In line with previous, enlightened studies that emphasised the importance of a new approach to the structural analysis of historic buildings; see Edoardo Benvenuto, *La scienza delle costruzioni e il suo sviluppo storico* (Firenze: Sansoni, 1981), E. Benvenuto et al., *Structural restauration of ancient*

case study—the Brandale Tower in Savona—where structural assessment was made possible thanks to a careful and detailed archaeological analysis of the structure.

Knowledge for Conservation

In a 1990 article published in the *Notiziario di Archeologia Medievale* (NAM), Tiziano Mannoni – the pioneer who, in the 1970s, laid the foundations of the Archaeology of Architecture – formulated the principle: *"To know in order to better preserve, and to preserve in order to better know"*.[3] Research on the Brandale Tower has fully embodied both of these aspects. The first phase of the work was devoted to an in-depth study of the structure, with the aim of ensuring its

monuments sujects to seismic risk: methological problems in *Annali della Fondazione Calisto Pontello - Marzo-giugno 1987: Tecnologia scienza e storia per la conservazione del costruito. Seminari e letture* (Firenze: Eurografica, 1988), 83-97; Salvatore Di Pasquale, *L'arte del costruire. Tra conoscenza e scienza* (Venezia: Marsilio editori. 1996); Salvatore Di Pasquale, *Il materiale muratura. Questioni strutturali ed esperienze di laboratorio* in *Archeologia dell'Architettura,* no. II (1997): 9-13; Antonino Giuffré, *Letture sulla meccanica delle murature storiche* (Roma: Kappa, 1991); Antonino Giuffré, A.(Ed.), *Sicurezza e conservazione dei centri storici. Il caso Ortigia* (Bari: Laterza, 2006), in recent years, particularly with the publication of the document Guidelines for the assessment and reduction of seismic risk to cultural heritage. Alignment with the new Technical Standards for Construction (Ministero per i Beni e le Attività Culturali, *Linee Guida per la valutazione e riduzione del rischio sismico del Patrimonio culturale. Allineamento alle nuove Norme tecniche per le costruzioni*, Roma), the relationship between stratigraphy, historical knowledge and structural assessment of buildings has been rethought. Several attempts have been made to address the issue of accurate knowledge of historical structures and, in particular, the need to define the actual load-bearing capacity of masonry, going beyond the application of abstract calculations and formulas designed for contemporary construction. In this regard, see the following bibliographical references: Gian Pietro Brogiolo, "Procedure di documentazione e processi interpretativi dell'edilizia storica alla luce delle Linee Guida per la valutazione e riduzione del rischio sismico del patrimonio culturale," in *Archeologia dell'architettura* no. XIII (2010): 9-13; Sergio Lagomarsino, and Anna Boato, "Stratigrafia e statica," in *Archeologia dell'architettura* no. XV(2011): 47-53; David Almeida Eleutério, "A Estratigrafia do Construído como um Objeto de Inquirição: Caso de Estudo das Insulae VI, 3–4 do Sítio Arqueológico de Pompeia (Campânia – Itália)," in *Atas do IX Encontro Nacional de Estudantes de História* (eds.) Ana Catarina Pereira et al. (Porto: Faculdade de Letras da Universidade do Porto, 2014), 15-30; Franco Braga, Walter Salvatore, Andrea Vignoli (Eds.), *Atti del XVII Convegno ANIDIS - L'ingegneria sismica in Italia, Pistoia 17-21 settembre 2017* (Pisa: Pisa University Press, 2017); Andrea Arrighetti, "Archeologia dell'architettura e terremoti," *Archeologia dell'Architettura* 23 (2018): 1-84; Paolo Faccio and Isabella Zamboni, "Archeologia dell'architettura e prevenzione. Metodi di primo livello per la valutazione di vulnerabilità sismica di complessi architettonici," in *VIII Congresso Nazionale di Archeologia Medievale* (eds.) F. Sogliani, B. Gargiulo, E. Annunziata, and V. Vitale (2018): 170-175; Rafael Martín Talaverano, Leandro Cámara Muñoz, and José Ignacio Murillo Fragero, "Análisis integrado de construcciones históricas: secuencia estratigráfica y diagnóstico patológico. Aplicación en la iglesia de Santa Clara (Córdoba)," *Arqueología de la Arquitectura* 15 (2018): e067; Pamela Michelle López Suscal and María del Cisne Aguirre Ullauri, "Technical Protocols of Heritage Preservation from Risk and Vulnerability Analysis: The Case of the Vernacular Architecture of Quingeo (Azuay, Ecuador)," *Arqueología de la Arquitectura* 20 (2023): e139; Stefano Barbò, "Danni sismici e stratigrafia degli elevati. Potenzialità e problematiche," *Archeologia dell'Architettura* 29 (2024): 115-130; Silvia Pinasco, Sergio Lagomarsino, and Serena Cattari, "Unreinforced Masonry Buildings in Aggregate of Urban Settlements: Current Approaches and Critical Issues for the Seismic Vulnerability Assessment," *Structures* 73 (March 2025): 108335.

3. Tiziano Mannoni, "Archeologia dell'architettura," in *NAM (Notiziario di Archeologia Medievale)*, no. 54 (1990): 29.

preservation. In turn, the process of conserving the materials and all historical traces proved to be a valuable tool for deepening the understanding of past construction techniques. By comparing these findings with data from other structures of the same period, it was possible to make significant progress both in the complex issue of preserving historic architecture and in assessing its actual structural resistance to stress. However, this understanding cannot be pursued by directly applying modern engineering formulas designed for reinforced concrete; it requires a specific approach, tailored to the peculiarities of ancient structures.

Questions

The specific research on the Torre Brandale was carried out within the framework of the *Retrofitting* course and formed the core of a master's thesis.[4] In fact, the Department of Architecture and Engineering had already been collaborating for some time on studies concerning the knowledge of ancient structures and the assessment of their actual static resistance.[5] With regard to the archaeology of architecture in particular, the investigation covers a broad time span, from the Middle Ages to the contemporary era, as some significant modifications occurred relatively recently. The tools and methodologies adopted in this study are based on research conducted by the author between 2016 and 2019.[6] The project is part of a broader research plan already started some years ago. This research plan includes several PRAs (University Research Projects), of which the scientific director for all is prof. Daniela Pittaluga in some cases in cooperation with professors of other foreign universi ties. In particular, on the issues of conservation and enhancement of port structures, we worked with the 2016 PRA with a project on "The archeology of architecture in the restoration site" of the Universidad del Pais Vasco- Facultad

4. Camilla Sbardella, *Brandale Tower: Construction Analysis and Structural Diagnostic* (University of Genoa, a.a. 2020–2021), rel. Chiara Calderini, corr. Carlo Battini e Daniela Pittaluga.

5. See Anna Boato, Sergio Lagomarsino and Daniela Pittaluga, "Masonry Vaults in Genoa: From Historical and Archaeological Analyses to Scientific Interpretation of the Rules for Their Construction," in *Proceedings of the First International Congress on Construction History* (Madrid, 20–24 January 2003), vol. 1 (Madrid: Instituto Juan de Herrera, 2003), 391-403; Chiara Calderini, Andrea Canziani, Sergio Lagomarsino and Daniela Pittaluga, "Structural Framework Evolution from the 17th to 20th Century in the Genoa Republic's Shipyard. Architectural Archaeology Investigates the Layers of Structure," in *Proceedings of the Second International Congress on Construction History* (Cambridge: Construction History Society, 2006), 473-492; F. Caterina Carocci et al., "Una metodologia per la conservazione dei centri storici danneggiati dal sisma: rilievo costruttivo e del danno, indagini ed indicazioni per il recupero di Casentino (AQ)," in Giousé Boscato, Francesco Guerra, Salvatore Russo, Francesco Sciarretta, e Elena Sperotto (eds.) *Sicurezza e conservazione nel recupero dei beni culturali colpiti da sisma. Strategie e tecniche di ricostruzione ad un anno dal terremoto abruzzese. Atti del convegno, Venezia, 8–9 aprile 2010* (Venezia: Università IUAV di Venezia, 2010), 282-291.

6. See Simonetta Acacia, Roberto Babbetto, Marta Casanova, Elena Macchioni and Daniela Pittaluga, "Photogrammetry as a Tool for Chronological Dating of Fired Bricks Structures in Genoa Area," *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* XLII-2/W5 (2017): 749-753; Daniela Pittaluga, "Evoluzione del degrado e analisi stratigrafica," in Stefano F. Musso (ed.) *Recupero e restauro degli edifici storici. Guida pratica al rilievo e alla diagnostica* (Roma: EPC, 2016), 514-517; Daniela Pittaluga and Fabio Fratini (Eds.), *Conservation et mise en valeur du patrimoine architectural et paysagé des sites côtiers méditerranéens* (Milano: FrancoAngeli, 2019).

de Letras, Departamento de Geografia, Prehistoria y Arquelogia, PRA 2018 with a project on "Conservation and restoration: methods of analysis and monitoring strategies" with CISAPSI- Inter-municipal coordination of studies and analysis of the historical heritage of Switzerland Italy, PRA 2019 with a project on "Conservation and restoration: methods of analysis and maintenance strategies of material and restoration: strategies for a quality project" .

Archaeology of Architecture and Static Knowledge

What is meant by "archaeology of architecture"? When was this approach to the study of ancient buildings developed? And how can it contribute to understanding historic structures, to the design of their restoration, and to their structural consolidation?

Archaeology of Architecture

By the mid-1970s, it became clear that, for the purposes of historical interpretation, it was too limiting to focus solely on excavating vanished settlements and producing graphic reconstructions of them, without taking into account the large number of contemporaneous buildings that still survive. Of course, there are evident differences—both in research methods and in the type of information obtainable—between lost buildings and surviving ones: in the former, the lower levels preserve traces of uses and arrangements "frozen" at the moment of destruction or abandonment; in the latter, such evidence is absent, as the structures have changed over time—sometimes radically—and have often undergone maintenance work. Nevertheless, these buildings are still standing and do not require, as excavated remains do, the painstaking study of collapses in order to reconstruct their form, even partially. It was at this point that architects began to recognise the value of different methods—both archaeological and archaeometric—while archaeologists came to understand that cognitive analysis could serve a practical purpose in the conservation of historic architecture. From this collaboration between archaeologists and architects, archaeology of architecture emerged as an autonomous discipline, and since then it has made significant progress.[7] The archaeology of architecture is therefore "…è

7. Below are some bibliographical references, mostly referring to the Genoese school; studies on this discipline have grown significantly in recent years in various Italian contexts and beyond. This is not the place for a more exhaustive examination, so we have decided to provide some basic references and refer to other sources for more complete and detailed lists. For a definition of 'architectural archaeology', see: Mannoni, "Archeologia dell'architettura", 1990; Anna Boato, Daniela Pittaluga, "Building Archaeology: A Non-Destructive Archaeology," paper presented at the *15th World Conference on Non-Destructive Testing*, Roma, 2000, *e-Journal of Nondestructive Testing*; Anna Boato, *L'archeologia in architettura: Misurazioni, stratigrafie, datazioni, restauro* (Venice: Marsilio, 2008); Gian Pietro Brogiolo e Aurora Cagnana, *Archeologia dell'architettura: metodi e interpretazioni* (Firenze: All'Insegna del Giglio, 2012). For specific research on stone, brick and earth constructions, see Alessandra Casarino and Daniela Pittaluga, "An Analysis of Building Methods: Chemical-Physical and Archaeological Analyses of Micro-Layer Coatings on Medieval Facades in the Centre of Genoa," *Journal of Cultural Heritage* 2, no. 4 (2001): 259-275; Anna Boato, Daniela Pittaluga, "Un impegnativo intervento secentesco di sottomurazione nel monastero di Santa Maria delle Grazie a Genova,"

certo una disciplina (teorico-pratica?) ma, in realtà, è molto di più…E' un habitus mentale, è una pensosa, prudente e impegnativa via di apertura al mondo ignoto del passato, attraverso la frequentazione e il contatto diretto con le sue tracce materiali… Essa è l'espressione e, insieme, il concreto esercizio di una costante e pacata consapevolezza della parzialità e, talvolta, della provvisorietà degli esiti dei nostri studi, dei limiti della nostra capacità di comprensione, del rischio dell'errore e della potenza scatenante del dubbio".[8]

Archaeology of Architecture and the Static Behavior of Structures: A Necessary Dialogue

What relationship exists between the archaeology of architecture and the analysis of the static behavior of buildings? Why is knowledge of the historical transformations of a construction relevant to those studying its stability and safety? The archaeology of architecture – or above-ground archaeology – makes it possible to identify and interpret all the transformations that a building complex has

Archeologia dell'architettura 7 (2002): 99-134; Daniela Pittaluga, "La mensiocronologia dei mattoni. Per datare, per conoscere e per comprendere le strutture storiche," 2009b, Genova: ECIG; Tiziano Mannoni, Aurora Cagnana, Stefano Falsini, Paola Ghislanzoni, Daniela Pittaluga, "Archeologia ed archeometria dei muri in pietra. Superfici e strutture in Liguria," in *Le pietre nell'architettura: struttura e superfici* (eds.) G. Biscontin, D. Mietto, Convegno di Studi Scienza e Beni Culturali, Bressanone, 25–28 giugno 1991 (Padova: Libreria Progetto Editore, 1991), 151-162; Daniela Pittaluga, Alessia Di Rocco, Clarissa Casagrande, Silvia Guerinoni, and Giulia Pellegri, "Historical earthen walls: From knowledge to conscious conservation," *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* 44 (2020): 1117-1124; Fabio Fratini, Mounsif Ibnoussina, Karima Mazirh, Brahim Boudad, Rachida Kasimi, Mohamed Nocairi, et al., Silvia Rescic and Omar Witam, "Characterisation of the materials and construction techniques of Sahrij Labgar: a thousand-year-old abandoned hydraulic structure (Marrakech, Morocco)," *Intrecci – International Journal of Architectural Conservation and Restoration*, no. 5 (2024): 25-43. For the relationship between architectural archaeology and restoration, see Daniela Pittaluga, *Questioni di archeologia dell'architettura e restauro* (Genova: ECIG, 2009a); Stefano F. Musso, "Analisi stratigrafica (studio) versus prevenzione e restauro (azione)," *Archeologia dell'architettura* XV (2010 [2011]): 107-113; Francesco Doglioni, "Leggibilità della costruzione, percorsi di ricerca stratigrafica e restauro," *Archeologia dell'architettura* XV (2010 [2011]): 65-79. And for the relationship between architectural archaeology and study and restoration of small villages see Lamia Hadda, Saverio Mecca, Giovanni Pancani, Massimo Carta, Fabio Fratini, Stefano Galassi, et al., "Villages et quartiers à risque d'abandon. Stratégies pour la connaissance, la valorisation et la restauration," *Villages and Neighbourhoods at Risk of Abandonment: Strategies for Knowledge, Enhancement and Restoration* (Firenze: Firenze University Press, 2022), 1-268. For the latest developments in the archaeology of more recent architecture, see Daniela Pittaluga, "L'analisi archeologica per la conoscenza e la conservazione delle strutture del XX secolo," in *Tiziano Mannoni. Attualità e sviluppi di metodi e di idee*, ed. ISCuM, 436-443 (Firenze: All'Insegna del Giglio, 2021); Daniela Pittaluga, "The archaeology of architecture for the knowledge and preservation of the 'modern'," *Restauro Archeologico* 30, no. 1 (2022).

8. "It is certainly a discipline (theoretical-practice?), but in reality it is much more than that... It is a mental habitus, a thoughtful, prudent and demanding way of opening up to the unknown world of the past, through frequentation and direct contact with its material traces... It is the expression and, at the same time, the concrete exercise of a constant and calm awareness of the partiality and, at times, the provisional nature of the results of our studies, of the limits of our capacity for understanding, of the risk of error and of the unleashing power of doubt" (Stefano F. Musso, "Analisi stratigrafica (studio) versus prevenzione e restauro (azione)," *Archeologia dell'architettura* XV (2010): 108).

undergone over time. This historical perspective is essential for the structural engineer who, in studying the static behavior of a structure, cannot limit their assessment to the thickness of walls and the loads they bear.[9] The response of a wall, in fact, varies significantly depending on whether it was built in a single construction phase with homogeneous materials, or whether it derives from the juxtaposition of portions erected in different periods, with different materials and techniques. In the latter case, it becomes necessary to determine:

- whether the adjoining parts are made of similar or heterogeneous materials;
- whether there are connections between the different wall sections, and whether these were deliberately made (for example, as preventive expansion joints) or resulted from construction limitations;
- the static effectiveness of such connections and their distribution;
- the relationship between the masses and volumes of the preexisting and added wall sections, as well as their relative chronology.

These aspects directly affect the load-bearing capacity of the structure. A new section added against a solid wall may not compromise its resistance; on the contrary, connecting it to an already fragile wall can trigger progressive degradation processes, even without causing immediate collapse. A stratigraphic analysis is also indispensable in cases of functional changes: elements originally conceived as non-load-bearing that over time become partially load-bearing; structures subjected to loads greater than those initially planned; or weight transfers due to local settlements that impose thrusts on parts not designed to receive them. Another contribution of the archaeology of architecture lies in identifying and dating repair interventions. Assessing the present condition of such consolidations allows one to estimate their effectiveness and to understand ongoing degradation processes. Similarly, archaeological interpretation clarifies situations that only integrated static analysis can explain correctly: for example, a buttress added later to counteract the rotation of a wall is less effective than a buttress built simultaneously with the wall itself.

Observation Criteria Useful to the Structural Engineer

The archaeological analysis of standing structures provides engineers with a set of indicators to observe carefully:

- *Wall anomalies*: deviations in wall alignment, out-of-plumb, bulges, breaks in continuity.
- *Construction joints*: their presence signals suspensions and resumptions of the building process. Vertical joints more easily generate differential movements, while horizontal ones are often less critical and harder to detect.[10]

9. AA.VV., *Linee guida per la valutazione e riduzione del rischio sismico del patrimonio culturale. Allineamento alle nuove Norme tecniche per le costruzioni* (Roma, 2010).

10. Sergio Lagomarsino, and Anna Boato, "Stratigrafia e statica," *Archeologia dell'architettura* XV (2011): 51.

- *Plan surveys*: heterogeneous wall thicknesses or unusual alignments may indicate different construction phases. For example, if the floor plan shows significant differences in wall thickness that cannot be justified by different functions, these could be the result of work carried out at different times and perhaps even with different materials and techniques.
- *Changes in materials or construction techniques*: these may indicate different phases, unless due to contingent choices during construction.
- *Subsequent modifications:* even minor interventions, if numerous and close together (e.g., openings cut and then sealed), can compromise the local resistance of walls.
- *Workmanship of individual elements*: useful for dating and recognizing additions or enlargements.
- *Quality of materials and workmanship*: assessments often requiring laboratory analysis and historical documentation (e.g., archival documents that may be descriptive or even prescriptive in nature).[11]
- *Protective measures:* detect the presence of protective measures (in certain areas, these may also be actual anti-seismic measures, either ancient or recent) capable of improving the static behaviour of the building
- *Comparison with contemporary and local buildings:* useful for understanding techniques, materials, and construction choices of the context.
- *Widespread interventions*: traces of regulatory adaptations (e.g., anti-seismic measures) that historically affected multiple buildings in an area.[12]

Method and Integration of Analyses: The archaeology of architecture begins with stratigraphic observation of wall surfaces. Although it may seem reductive to infer the behavior of an entire section from a surface, in many cases – such as with homogeneous exposed masonry of limited thickness – it already provides sufficiently reliable information. When data are inconclusive, stratigraphic investigation still helps localize problematic areas, to be further studied with targeted probes or complementary investigations using multiple methods. Integration between archaeological observation and structural analysis therefore makes it possible to guide investigations, optimize checks, and identify the most significant points of vulnerability. It is precisely in these areas that specific analyses and, if necessary, consolidation interventions should be planned. In conclusion: The construction history of a building is not merely of interest to historians or archaeologists: it represents indispensable knowledge for engineers as well. The archaeology of architecture, through its ability to reconstruct the material history of a structure, thus becomes an essential tool for understanding the static behavior of buildings and for designing conservation interventions that are both informed and respectful.

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11. Ibid, 52.

12. Following seismic events or the collapse of buildings or parts thereof due to inadequate construction methods, city magistrates or other authorities responsible for protecting communities could, for example, provide guidance on how to build from that point onwards in order to prevent a recurrence of the event. This not only helps us to chronologically attribute construction techniques (by providing a possibility of post quem dating), but can also shed light on why a particular solution was adopted.

The Brandale Tower in Savona (IT)

The Brandale tower in Savona is a symbol of this city. Medieval tower, former seat of the municipali-ty, is located in the historical centre of Savona in a district that still retains traces of a dozen historical towers. The Tower was therefore built directly facing the ancient 'Calata'. As shown by the existing documents, the Tower was originally privately owned and only at the beginning of the 14th century the property passed to the municipality. The oldest document attesting the existence of the tower dates back to May 1178. It was found in the documents of notary Arnaldo Cumano and certifies the sale to Arnaldo Iolta by On October 29, 1528, at the end of its second fight with Genoa, Savona sur-rendered to Andrea Doria. Disregarding the pacts es-tablished with the Elders of the city, the winners im-posed very heavy penalties on the city of Savona. In addition to the taxes and restrictions on traffic and navigation, the port was buried, the walls of the dock were dismantled and the towers were partially de-stroyed.Ansaldo Curlaspedo and his wife Richelda. On October 10, 1552, under the order of the rulers of Genoa, which was commonly called the 'Superba', the Elders were ordered to lower the Brandale Tow-er by 100 palms (half of its total height, which was 49.60 m). In 1800, the Brandale Tower and its surroundings underwent major renovations. One of the first pro-jects of the "A Campanassa" Association, founded in 1924, which had and still has its headquarters in the Brandale Tower, was to restore the tower to its orig-inal height of 49.60 meters. The works for the rais-ing of the Tower began in the summer of 1931, car-ried out by the Prefumo company, based on the pro-ject of the engineer Giovanni Damonte. The new floors were made, as the technical report states: "In partially reinforced cement conglomerate, so as to be able to obtain a good connection between the various parts of the monument, without resorting to large thicknesses of masonry".[13] At present, a rather advanced state of decay has imposed the need for an assessment of the structure's real state of conservation. A research project was prepared with agreements between the Municipality of Savona, local associations, and the university in order to better understand the tower's state of conservation and draw up guidelines for restoration. A detailed survey, an analysis of the materials and their state of conservation, and a stratigraphic analysis of the entire complex was carried out. Thanks to this study, it was possible to have a clear idea of the situation and to specify guidelines for its conservation. In many cases, an in-depth knowledge of the artefact makes it possible to achieve high levels of sustainability on the restoration site: in fact, it minimises interventions, while at the same time making them more effective. In the case of the Brandale Tower, this was possible. Preserving the Torre del Brandale is not only the preservation of an important building, but it is the preservation of a part of the city, for the role it played

13. G. Damonte, "La sopraelevazione della Torre del Brandale," *La proprietà edilizia della Provincia di Savona* 1–2 (maggio 1931). The technical report of Damonte's project called for the use of "partially reinforced concrete construction". This choice was crucial to ensuring a solid structural connection between the various historical parts of the monument without burdening the ancient structure with thick masonry. The tower had been historically truncated (reduced in height). Thanks to this intervention in the 1930s, the structure was restored to its majestic original height of 49.60 meters. The full printed text is preserved in the historical records of the *A Campanassa* Association.

as the seat of government and as an expression of a part of the city that is, for many, unknown today, the medieval city of Savona with its high towers.[14]

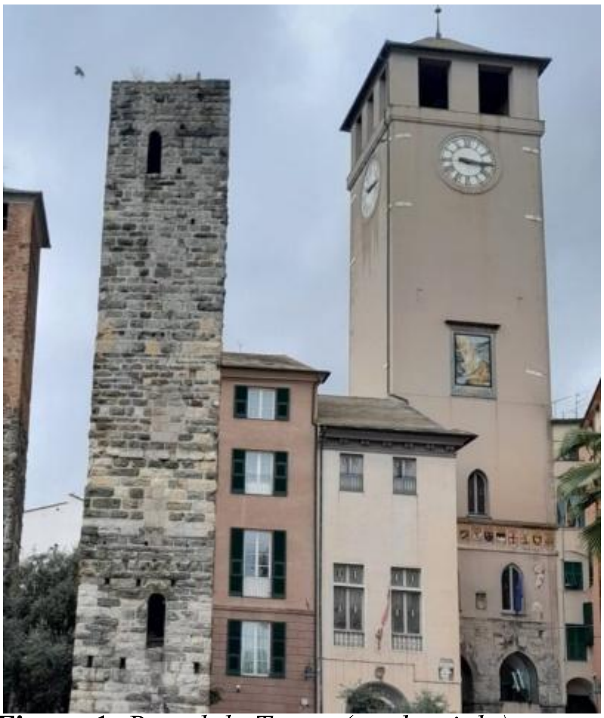


Figure 1. *Brandale Tower (on the right)*
Source: Pittaluga 2025.

Archaeological Analysis of Architecture Applied to the Brandale Tower

The Brandale tower (Figure 1) was the subject of a detailed archaeological study,[15] which provided essential information for subsequent structural analysis and for making the right decisions regarding the need for static consolidation. The archaeological study consisted of the following phases: 1) geometric survey, 2) analysis of materials and construction phases (Figure 2b), 3) stratigraphic analysis with identification of stratigraphic units (Figure 2a), recording on stratigraphic maps for all internal and external elevations, identification of stratigraphic relationships between SUs, 4) application of various dating methods such as 4a) analysis of masonry techniques, 4b) mineralogical-petrographic analysis of mortars, 4c) mensiochronological analysis of bricks and stones.This ultimately made it possible to refine a volume stratigraphy in which all the transformations that have affected the tower over the centuries are outlined. In the final part of this study, the information

14. Damonte, "La sopraelevazione della Torre del Brandale"; Poggio Poggi, "La Torre del Brandale," *La proprietà edilizia della Provincia di Savona* 1–2 (febbraio 1932); Poggio Poggi, *Il Brandale. Storia della torre del Brandale e dell'annesso Palazzo degli Anziani dalle origini ai nostri giorni* (Savona: Società Savonese di Storia Patria, Tipografia Savonese, 1936); A. Berruti, E. Curti, and B. Menghi, *Restauro del complesso della torre del Brandale* (Savona, 2014–2015), fondo monumentale, Savona, mon. 31, parte IV, archivio della Soprintendenza Archeologia, Belle Arti e Paesaggio per la Città Metropolitana di Genova e la Provincia della Spezia.

15. Pittaluga, *Questioni di archeologia dell'architettura e restauro*.

was organised into a hierarchy: first, the significant stratifications of volume were described and analysed, i.e. those with major changes in volume, then the changes that may have affected the horizontal structures (floors, vaults), then the changes that affected the openings/closures of doors and windows, and finally the visible layers in the coatings (successive plastering, multiple layers of paint, etc.). Only after gaining such a precise understanding of the historical object was an analysis of the currently visible cracks carried out. In this study, since the client's (Associazione "A Campanassa") primary concern was to understand the real danger or otherwise of structural instability in the tower, we wanted to introduce a variable that is not usually included in this context: in this case, a stratigraphic study of the cracks was carried out, so to speak, i.e., an attempt was made to determine which cracks showed traces of previous grouting and which did not. In this way, it is possible to obtain a preliminary overview of the instability over time (details on this aspect are provided in the next paragraph). Cracks with traces of old grouting are a sign of instability that occurred in the past and was remedied, cracks with traces of plastering but which have reopened indicate that the cause that had caused them in the past has reoccurred, cracks without any traces of plastering are the most recent cracks, the cause of which has not yet been remedied, and then the effect produced. In order to determine the chronology of the onset of the cracks, it can sometimes be useful to compare the stratigraphy of the coatings and masonry: in these cases, and not always, it is only possible to obtain a date ante or post quem.[16]

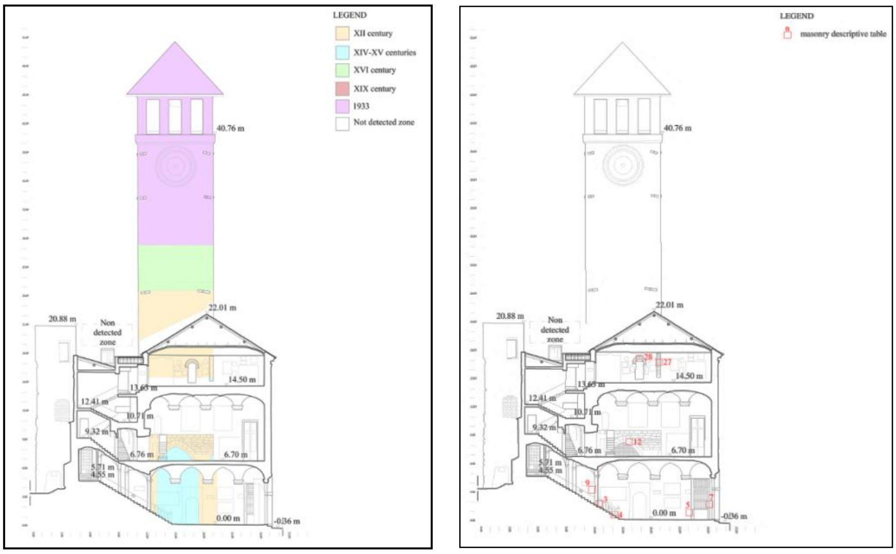


Figure 2. *Brandale Tower: Material Map (Fig. 2a) and Stratigraphic Units (S.U.) (Fig. 2b)*
Source: Sbardella 2021, 5 and tab.A12.

16. For example, if the damage affects a portion of 18th century masonry but does not continue into the part of the wall raised in the 19th century, this is a sign that the damage had a cause that is no longer active; conversely, if the crack continues uninterrupted from the 19th-century masonry above to the 18th-century masonry below, it is a sign that the damage was caused in a more recent period, at least after the construction of the 19th-century wall; however, we cannot say how long after.

Structural Condition and Crack Pattern Analysis

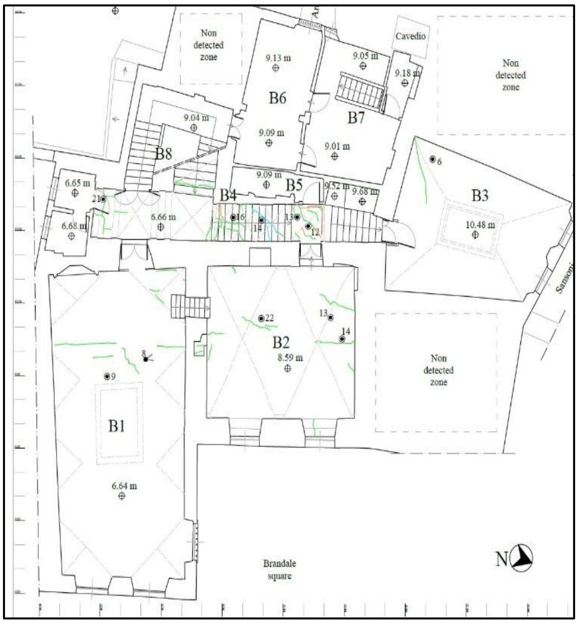
To assess the structural condition of the Brandale Tower and of the surrounding complex, a detailed survey of cracks and material degradation was carried out. Cracks were mapped in plans and sections and classified by width: thin cracks below 1 mm, medium cracks between 1 and 5 mm, and large cracks above 5 mm. Structural joints and previously repointed cracks were recorded separately, so that older discontinuities could be distinguished from more recent damage.

Structural Integrity and General Observations

The laser scanner survey showed that the tower is substantially vertical, with no relevant leaning, overturning or global deformation. Nevertheless, the survey identified a widespread but mostly localized crack pattern. The main causes are material discontinuities, old openings and fillings, imperfect connections between portions built in different phases, moisture, water infiltration and limited maintenance. The crack pattern must therefore be interpreted together with the construction history of the complex.

Vertical Elements

At the ground floor (Figure 3), thin cracks were mainly observed in the northern wall of room A1, where they correspond to material discontinuities and local installations. Moisture decay was also evident, with efflorescence, flaking of the plaster and deterioration of mortar joints, probably connected with rising damp and with the cistern below the tower. At the first floor (Figure 4) the crack pattern becomes more extensive.



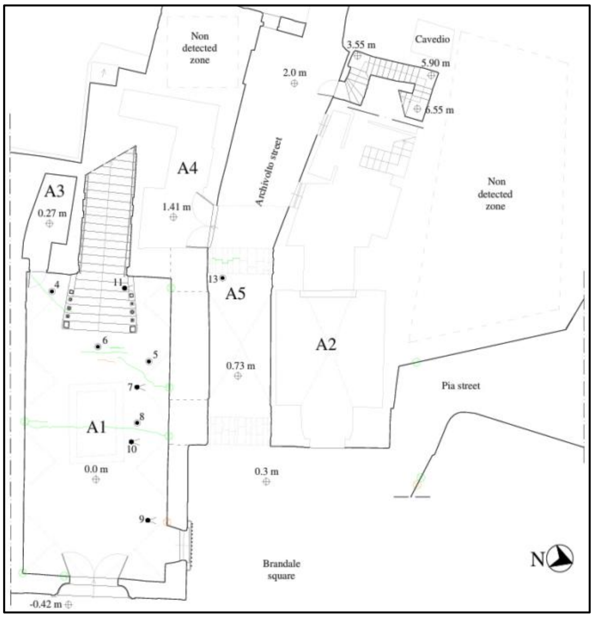


Figure 3. *Plan of the Ground Floor – Crack Pattern of Vertical Elements.*
Source: Sbardella 2021, 98.
Figure 4. *Plan of the First Floor – Crack Pattern of Vertical Elements*
Source: Sbardella 2021, tab F3b.

In room B1, cracks are associated with the joint between the tower and the Palazzo degli Anziani and with the infill of former openings; a medium vertical crack on the southern wall continues into the vault. In room B2, thin cracks occur around closed openings and at wall-vault junctions. Room B3 showed medium and large diagonal cracks, now covered by the 2021 repairs, which can be interpreted as the effect of past settlement rather than as evidence of an active mechanism (Figure 5).

Figure 5. *Crack Western Wall in Room B3*
Source: Sbardella 2021, 87.

Moisture-related decay had also affected the vault and walls of room B3. In room B4, cracks correspond both to old openings and to technical installations. In stairwell B8 and in room B6, vertical and diagonal cracks at wall intersections suggest weak connections between different building portions, especially where the tower, the Anziani Palace and the Gambarana Tower meet. On the second floor (Figure 6), cracks in room C1 are concentrated at corners and at the niche facing room C2, confirming the role of discontinuities and imperfect wall-to-wall connections (Figure 7).

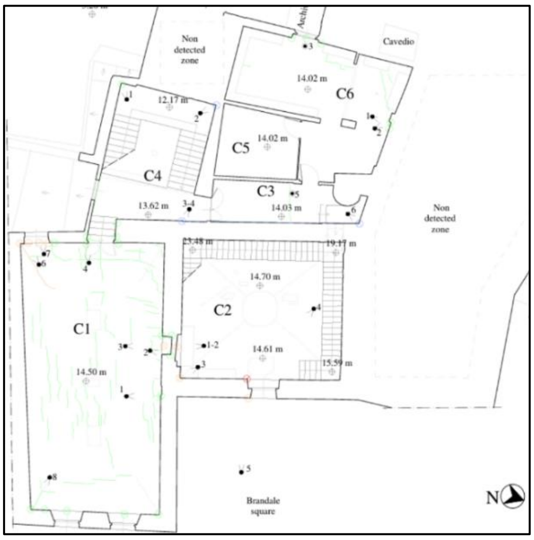


Figure 6. *Plan of the Second Floor – Crack Pattern of Vertical Elements*
Source: Sbardella 2021, 101.

Figure 7. *Vertical Cracks on the Opposite Side of the Wall Above the Niches in Rooms C1 (left) and C2 (right)*
Source: Sbardella 2021.

Moisture damage was also observed. Room C2 is particularly significant: its walls show masonry losses, worn mortar joints and a vertical crack above the eastern window, visible on both the inner and outer faces. The enlargement of the ogival window for the passage of the bell probably increased the local vulnerability of this wall (Figure 8). Rooms C5 and C6 show minor cracks and moisture problems, probably related to inaccessible neighbouring apartments.

Figure 8. *Enlargement of the Window, Vertical Crack Above the Window and Worn Mortar Joints*
Source: Sbardella 2021.

At the upper levels, the cracks are mostly thin and concentrated in the twentieth-century concrete and concrete-block masonry, especially at corners, around openings and close to the clock faces. Some larger cracks had already been repaired during the 1991 works, when carbonation, reinforcement corrosion and concrete-cover detachment were recorded. Crack meters, some dated to 1957, confirm long-term monitoring of these vulnerable points. The belfry shows the most evident degradation of the modern part of the tower. Cracks affect parapets and pillars on both inner and outer faces and are mainly due to the expansion of corroded reinforcement bars after carbonation of the concrete (Figure 9). The steel frame supporting the bell is rusted and the timber planking closing the central slab opening is degraded.

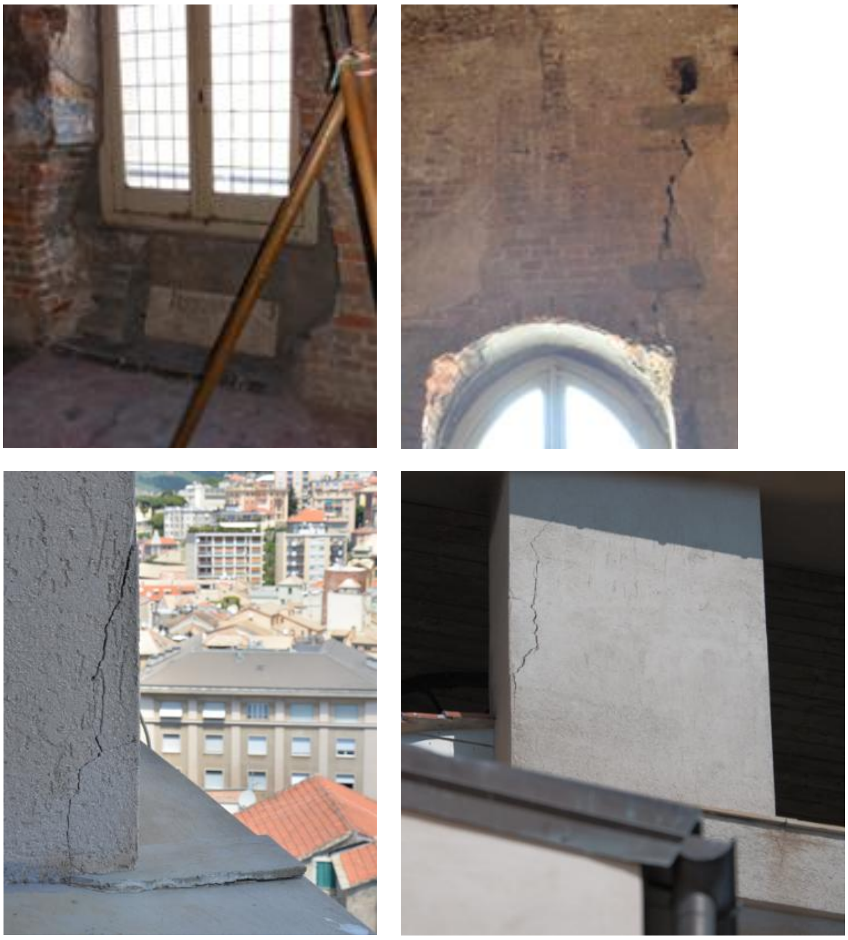


Figure 9. *Plan of the Fifth Floor and Crack Pattern of Vertical Elements*
Source: Sbardella 2021, 96.

Horizontal Elements

Cracking in the horizontal elements is less severe than in the vertical ones. At the ground floor, the tower vault shows only a minor crack along the western arch. In room A1, some cracks continue from the walls into the vault, again indicating the influence of structural discontinuities and embedded installations. At the first floor, cracks are present in the vaults of rooms B1, B2 and B3. The extrados of the vault in room B2 is not perfectly horizontal, with differences greater than 10 cm, but this appears to be related to construction irregularities rather than ongoing movement. The vault of room B3 was affected by water infiltration before the 2021 repair. In space B4 (Figure 10), several cracks, some previously grouted, show that this vault had already required local intervention.

Figure 10. *Plan of the First Floor - Crack Pattern of the Vault in Space B4.*
Source: Sbardella 2021, 99.

On the second floor, thin cracks affect the false ceilings of rooms C3-C6. Room C1 is the most critical, with widespread cracking and damp stains, probably related to construction defects identified in 2015. The vault of room C2 has no relevant cracks, although local masonry gaps are visible and the extrados is uneven (

Figure 11).

Figure 11. *Intrados of the Vault in Room C2.*
Source: Sbardella 2021, 102.

Finite Element Model of the Torre Del Brandale

A three-dimensional finite-element (FE) model of the Brandale Tower was developed in ANSYS Workbench to study its global structural and seismic behaviour. Because of the size and complexity of the building, masonry was represented through a macro-modelling approach: the masonry types identified by the architectural and material survey were modelled as homogenized isotropic continua, while preserving the main geometric irregularities and construction phases relevant to the global response.

Geometry

The FE geometry was derived from the laser-scanner survey and from the AutoCAD drawings. The three-dimensional solid model was first reconstructed in Blender and then imported into ANSYS (Figure 12).

Figure 12. *Model of the Tower Realized in Blender*
***Source*:** Sbardella 2021, 107.

All masonry walls were modelled with their surveyed thickness. In the double-leaf walls, the inner core and external brick faces were not represented separately, because their individual dimensions are small in relation to the whole model and their detailed geometry was not fully available.

Significant niches, passages and open or closed openings were included; where necessary (Figure 13), infill masonry was assigned a material different from the surrounding wall.

Minor elements, such as thin infills, window spandrels and staircases, were omitted because their influence on the global behaviour of the tower is limited. The timber roof was not directly modelled, but the loads transmitted by it were calculated and applied to the tower.

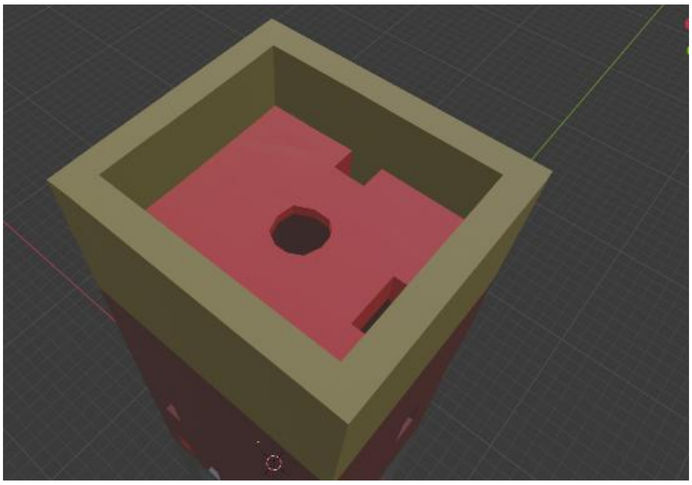


Figure 13. *Vault at the Third Level with Holes in the Center and on the East Side*
Source: Sbardella 2021, 109.

Finite Elements and Mesh

The mesh was generated in ANSYS. Two element types were used: three-dimensional solid elements for walls, vaults, slabs and reinforced-concrete members, and one-dimensional beam elements for the metal tie rods.

The solid parts were discretized with ten-node tetrahedral elements (TET10) with a feature size of 0.90 m. The tie rods were modelled with two-node beam elements, divided into eight or nine elements of about 90 cm each, and with circular sections corresponding to their measured diameters. The tie rod near the western wall at the second floor was not included because it was observed to be slack.

The final numerical model consisted of 194,867 nodes and 109,260 elements (Figure 14).

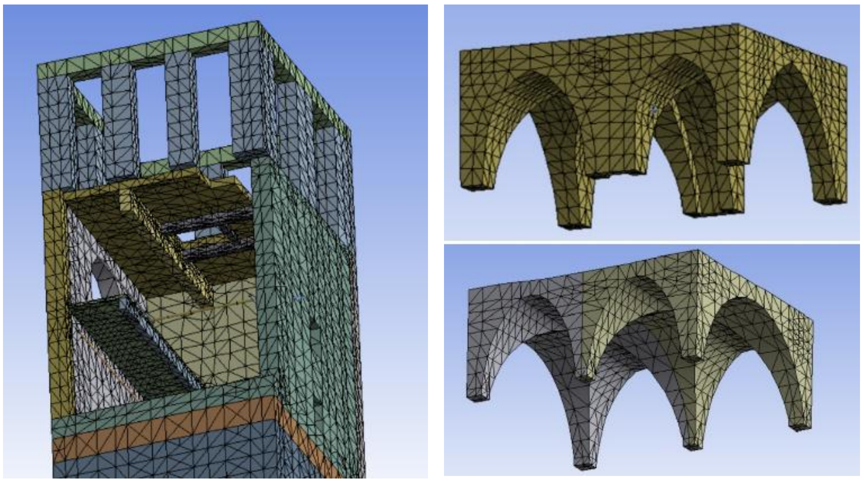


Figure 14. *Mesh Detail of Structural Elements Model-Led in Ansys*
Source: Sbardella 2021, 109-110.

Material Properties

Different material properties were assigned according to the construction phases identified by the survey (

Figure 15). The stone base was modelled as stone masonry (M1); the medieval walls and vaults as brick or double-leaf masonry (M2, M3); the sixteenth-century portions as mixed stone-and-brick masonry (M5); local infills as uncoursed mixed stone masonry or brick masonry (M4, M3); and the twentieth-century upper part as concrete-block masonry (M6) with reinforced-concrete beams, slabs and pillars.

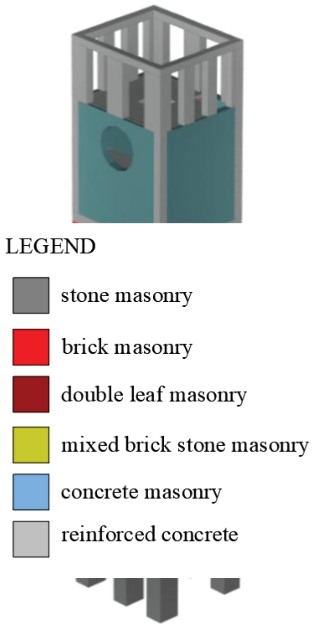


Figure 15. *Different Materials Shown in the Blender Model*
Source: Sbardella 2021, 122.

For the masonry types M1-M5, mechanical parameters were derived from Table C8.5.I of the Italian Building Code explanatory circular, taking into account the level of knowledge reached by the investigation (Table 1). Minimum values were adopted where the inner composition or the arrangement of the masonry was uncertain, for example in the double-leaf masonry and in mixed stone-and-brick walls. The concrete-block masonry of the 1933 reconstruction was defined according to Chapter 11.10 of the Italian Building Code.

Table 1. *Table C8.5.I - Reference Values of Masonry Mechanical Parameters*

Masonry tipology	f [N/mm^2]	τ_0 [N/mm^2]	f_{v0} [N/mm^2]	E [N/mm^2]	G [N/mm^2]	w [kN/m^3]
	min - max	min - max		min - max	min - max	
Stone masonry (M1)	5.8-8.2	0.09-0.12	0.18-0.28	2400-3300	800-1100	22
Double leaf masonry(M2)	2.6-4.3	0.05-0.13	0.13-0.27	1200-1800	400-600	18
Solid brick masonry (M3)	2.6-4.3	0.05-0.13	0.13-0.27	1200-1800	400-600	18
Uncoursed stone masonry with some brick pieces (M4)	1.0-2.0	0.018-0.032	-	690-1050	230-350	19
Mixed stone and brick masonry (M5)	2	0.035-0.051	-	1020-1440	340-480	20

Source: Sbardella 2021, 123.

The nonlinear behavior of masonry was described through an elastic-perfectly plastic model with a Drucker-Prager failure criterion available in ANSYS, which allows tensile/traction-compression and compressive failure surfaces to be represented.

Tensile strength, biaxial compressive strength and fracture nergy were assigned consistently with the adopted constitutive model.

The reinforced-concrete elements were modelled with the same elastoplastic criterion. Since direct tests on the tower concrete were not available, the adopted parameters were inferred from tests carried out on concrete specimens from the former San Paolo hospital in Savona, a building designed in the same period and by the same engineer. Steel tie rods were assigned a hardening elastoplastic law with standard steel properties.

Boundary Conditions and Loading

The base of the tower was fully restrained to simulate foundation embedment. The interaction with the adjacent buildings was represented by external constraints placed where the tower is connected to the Sansoni building, to the Anziani Palace and to the western stair structure. Self-weight was included, and the loads transmitted by the roof, floors and neighbouring buildings were applied to the corresponding parts of the model.

Overall, the FE model reproduces the as-surveyed tower at the scale required for a global assessment: it includes the main geometry, openings, construction phases, material distinctions, tie rods, external constraints and gravity loads. This choice is consistent with the aim of the study, which is not the detailed modelling of single stones or bricks but the interpretation of the tower's overall structural behaviour.

Nonlinear Static (Pushover) Analysis Results

The seismic response of the Brandale Tower was assessed by means of nonlinear static, or pushover, analyses in the two principal horizontal directions of the model, identified as X and Z. In this procedure, lateral forces are gradually increased over the height of the structure after the application of gravity loads, and the response is described by capacity curves relating base shear to the horizontal displacement of control points.

According to Eurocode 8, two lateral load distributions may be considered. In this study, a uniform distribution proportional to mass was adopted. Self-weight and the loads transmitted by the roof and adjacent buildings were applied first; then the horizontal forces were incrementally increased. Four nodes located at the top of the tower, near the edges of the opening in the last reinforced-concrete slab, were used as control points. The capacity curves were obtained from the average displacement of these nodes, while the corresponding acceleration was calculated from the base shear and the total mass.

Pushover in Z Direction

The analysis in the Z direction represents the most demanding case, because the tower has its smaller plan dimension and therefore lower thickness in this direction. The capacity curve in Figure 16 shows the relationship between base shear and the average top displacement, together with the corresponding acceleration-displacement curve.

The maximum acceleration reached in this direction was approximately 2.11 m/s², which is considerably higher than the reference seismic acceleration for the Savona area, about 0.55 m/s². Within the assumptions of the model, this indicates a relevant safety margin in the critical direction.

The tensile-stress and plastic-strain distributions (Figure 17) show that nonlinear effects are not uniformly spread throughout the tower. Plastic deformation is concentrated in a localized area at a certain height of the structure, confirming that the response is governed by specific discontinuities and by the geometry of the tower rather than by a generalized instability of the whole body.

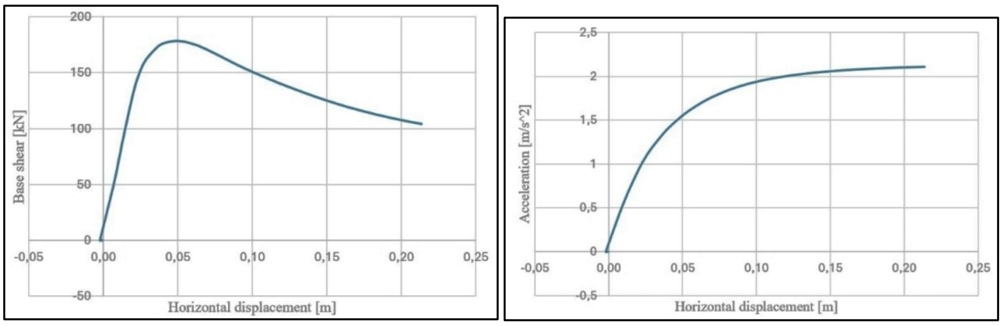


Figure 16. *Case with Acceleration along Z - Curve Base Shear vs Horizontal Displacement (Fig. 16.a) and Curve Acceleration vs Horizontal Displacement (Fig. 16.b)*
Source: Sbardella 2021, 129.

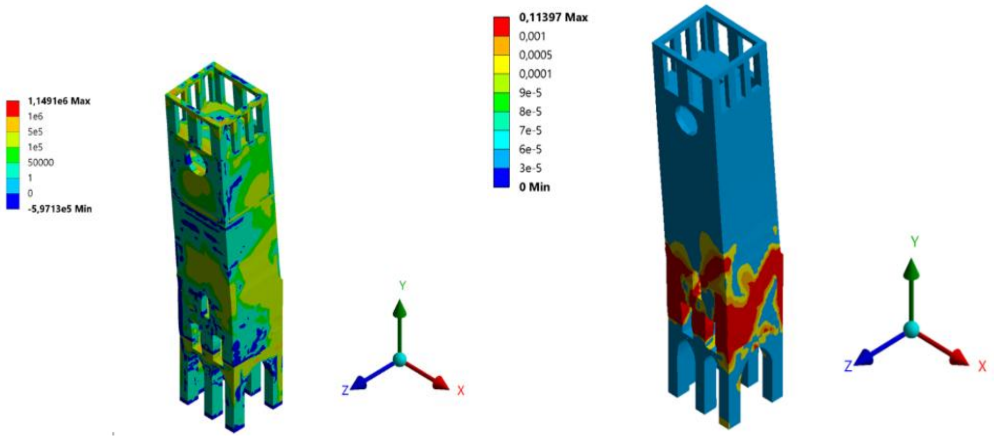


Figure 17. *Deformed Configuration with Acceleration along Z - Distribution of Tensile Stresses (17.a) Distribution of Plastic Deformations (17.b)*
Source: Sbardella 2021, 130.

The Z-direction results therefore identify the weakest orientation of the tower, but they do not indicate immediate global collapse under the considered seismic demand. They also help relate the numerical response to the survey, where cracks and material weaknesses are concentrated near openings, construction joints and modified portions of the masonry.

For this reason, the Z direction was used as the reference case for the interpretation of the seismic vulnerability of the tower.

Pushover in X Direction

The same procedure was repeated by applying the horizontal forces along the X direction. In this direction the tower has a larger plan width and the numerical response is therefore more resistant than in the Z direction, although the curve is also influenced by the different boundary conditions imposed by the connections with adjacent structures.

The maximum acceleration reached in the X-direction analysis was about 2.8 m/s², again much higher than the reference value of about 0.55 m/s² for Savona. Owing to the complexity of the model and the high number of nodes, the analyses required significant computational effort. The capacity curves were therefore plotted up to the last step reached within the available calculation time; this step should not necessarily be interpreted as the absolute final capacity of the building.

As in the Z-direction analysis, the tensile-stress and plastic-strain maps show localized concentrations of damage at a certain height of the tower. The X-direction response confirms the role of geometric discontinuities and openings, but it is less critical than the Z-direction response because of the greater structural width.Figure 18 reports the base-shear/displacement and acceleration/displacement curves for the X-direction pushover.

The comparison between the two analyses shows that the tower has a higher capacity in the X direction, while the Z direction is the controlling case. In both cases, the calculated accelerations exceed the seismic demand considered for the site. The results must nevertheless be read in relation to the modelling assumptions and to the limits of the available information, especially for the connections with adjacent buildings and for the twentieth-century reinforced-concrete part.

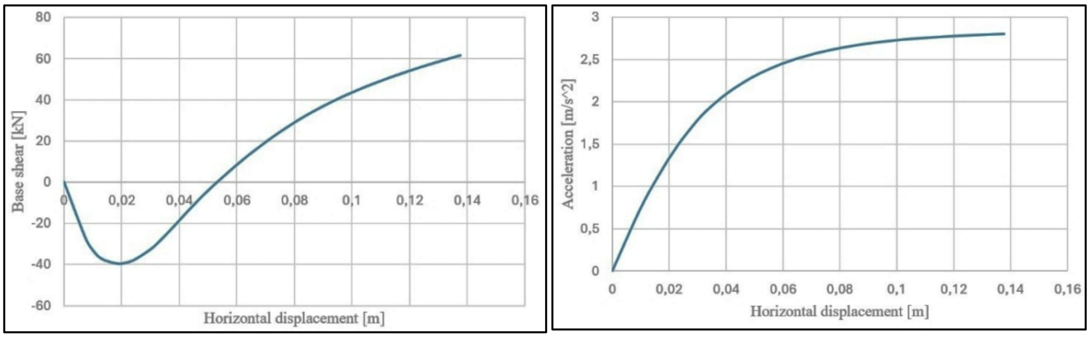


Figure 18. *Case with Acceleration along X - Curve Base Shear vs Horizontal Displacement (Fig. 18.a) and Curve Acceleration vs Horizontal Displacement (Fig. 18.b)*
Source: Sbardella 2021, 131-132.

Interpretation

In the adopted FEM model, the Torre del Brandale shows a global seismic capacity significantly higher than the seismic demand expected for the site of Savona. The nonlinear static analyses indicate that, at the scale of global behaviour, the Torre del Brandale does not present significant seismic deficiencies under the analysed conditions. This result is consistent with the damage survey, which did not reveal relevant phenomena of tilting, overturning, or severe active cracking patterns within the masonry structure. The vulnerability does not appear to be associated with a generalized collapse of the entire masonry organism, but rather with localized phenomena concentrated around openings (especially modified openings), geometric discontinuities (caused by different construction techniques, different materials, and decay), and joints between different construction phases. Four distinct construction phases were identified, the last of which dates to 1933 and involved substantial and invasive modifications. The Z direction represents the most critical case due to the smaller plan dimension and the resulting reduction in stiffness. However, the interpretation of the results must take into account the limitations inherent in the homogenized macro-model, as well as the uncertainties related to the connections with adjacent buildings and the characterization of the historic materials. These findings support a conservation strategy based on further targeted investigation, monitoring and localized interventions, designed to remain compatible with the historic materials and as reversible as possible.

Conclusion

In the history of construction, there are many reasons for modifying a building: changes in function, improvements in use, aesthetic or fashion-related requirements, voluntary or regulatory structural adjustments, interventions to combat material degradation or to remedy various types of structural instability. All these factors are significant, not only for reconstructing the history of the building, but also for understanding its real static resistance capacity. Even seemingly marginal transformations, such as those dictated by aesthetic requirements, can have significant consequences on structural behaviour: for example, the different distribution and size of openings, the elimination of internal partitions in favour of large open spaces, or the presence of cladding on the facades. It is therefore essential not to overlook this information, while avoiding overloading the data set, since the ultimate goal remains the assessment of the overall resistance of the building and the identification of its current and future vulnerabilities. From the point of view of the historian or archaeologist, the archaeological investigation aims above all to reconstruct the history of the building, as well as the economic and social context that determined its original layout and subsequent transformations.[17] The historian therefore tends to privilege man over his material achievements.[18] The perspective of an architect tasked with restoration is different, as they must ensure the preservation of the building's historical stratification, avoiding – as far as possible – erasing the traces of previous transformations.[19] The restoration work itself becomes a new layer to be added, rather than an element that cancels out the previous ones. For the architect or engineer called upon to verify structural safety, the archaeological investigation must instead reconstruct the history of damage and repairs, assessing their effectiveness. In this sense, differences between different archaeological interpretations are inevitable, as they are conditioned by the objectives of the analysis. As Francesco Doglioni observes, it is unrealistic to think of a single procedure that is valid for every case; it is more convincing to outline flexible methodological approaches that can be adapted to the nature of the artefacts and the purposes of the stratigraphic analysis.[20] From an archaeological perspective aimed at assessing static behaviour, the description of materials must be accompanied by data on construction techniques, assembly and mechanical parameters.[21] Information on deterioration and instability must be correlated with repairs, also assessing the recurrence of similar problems over time and the diversity of the interventions adopted. This allows for reflection on the effectiveness of the solutions undertaken. It is clear that masonry subjected to continuous modifications will have different static behaviour compared to a more intact portion. Furthermore, compared to a purely historical analysis, the study of the context takes on particular importance here: surveys of the ground, inspections of the foundations, assessment of adjacent buildings and their effects on the

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17. Gian Pietro Brogiolo, "Dall'archeologia dell'architettura all'archeologia della complessità," *Pyrenae. Revista de Prehistòria i Antiguitat de la Mediterrània Occidental* 38, no. 1 (2007): 7-38.

18. Tiziano Mannoni, "Archeologia e storia della mentalità," *Notiziario di Archeologia Medievale* 32 (1982): 3; Giovanni Murialdo, "Homo faber," in *Archeologie. Studi in onore di Tiziano Mannoni* (eds.) Nicola Cucuzza, and Massimo Medri (Bari: Edipuglia, 2006), 397-99.

19. Paolo Torsello, "Archeologia dell'elevato e restauro architettonico," in *Archeologie. Studi in onore di Tiziano Mannoni* (ed.) Nicola Cucuzza, and Massimo Medri (Bari: Edipuglia, 2006), 511-13.

20. Francesco Doglioni, "Questioni di gradualità e adattabilità operativa dell'analisi stratigrafica," *Archeologia dell'Architettura* 29 (2024): 8.

21. Gian Pietro Brogiolo and Paolo Faccio, "Stratigrafia e prevenzione," *Archeologia dell' Architettura* 15 (2011): 55-63.

structure. This attention must lead to a phase of critical selection of existing and foreseeable vulnerabilities, so as to focus the investigations on the areas most at risk.

This is the methodology followed, for example, in the case study of the Torre del Brandale. The tower, in fact, combines several complexities: it alternates between exposed masonry and plastered surfaces, preserves medieval elements alongside 20th-century transformations, and is located in a peculiar position, partially isolated on the square but at the same time incorporated into the historical fabric of Savona. This makes it a paradigmatic case for the study of other structures in similar contexts. The analysis highlighted how the transformations that have taken place over time have progressively modified the static behaviour of the tower, imposing new loads in areas that were not previously stressed. It is therefore essential to approach the conservation project with an interdisciplinary approach, integrating architectural archaeology, restoration and structural engineering. Seismic Ordinance 3274 of 2003 (and subsequent updates in 2008 and 2009)[22] had already emphasised the importance of the level of knowledge of the building, linking it directly to the safety coefficients to be adopted and introducing calculation models more in line with reality.[23] Much has been said about the adequacy of traditional calculation models, which are often overly simplified and based on the assumption of homogeneous materials and thicknesses, in contrast to the complexity of historic buildings. In a sense, it has been a debate between archaeologists and engineers. In the case of the Torre del Brandale, the preliminary analysis – although not fully transposed into the final model – was essential for identifying critical issues and correctly guiding subsequent checks. This highlights the importance of an "archaeological" knowledge of the building, capable of capturing every transformation, from the most macroscopic to the most minute, without considering the latter to be irrelevant. This knowledge does not belong solely to historians but becomes an indispensable tool for engineers in their structural assessments. This detailed and accurate study made it possible to understand that the structure is mainly affected by a "local" vulnerability rather than a "global" one.

From a conservation perspective, these results suggest that a general strengthening of the entire building is not necessary. Instead, it is more important to monitor the critical areas, control the evolution of cracks, and verify the connections between the different parts of the structure. Any interventions can therefore be limited to specific areas, such as openings, masonry bonds, modified sections, and wall connections. This approach makes it possible to respect one of the fundamental principles of conservation-restoration: minimum intervention. Acting only at a local level not only reduces the overall costs of the intervention, but also maximizes the preservation of the historic structure by increasing the amount of original material that remains intact and unaltered. The in-depth knowledge of the historic structure developed through this study also makes it possible to design truly compatible interventions. Although limited and localized, any interventions can be carried out using contemporary materials capable of ensuring a behaviour similar to that of the historic materials with regard to mechanical stress, thermal response, and moisture.

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22. Ministero per i Beni e le Attività Culturali, *Linee guida per la valutazione e riduzione del rischio sismico del patrimonio culturale*, 35.

23. Lagomarsino and Boato, "Stratigrafia e statica," 48.

In this way, it is possible to maintain a homogeneous structural behaviour despite differences in materials or finishes.

The archaeological analysis of the structure, which made it possible to accurately identify the different construction phases and transformations of the tower, as well as the joints between parts built in different periods, provided the essential basis for carrying out the subsequent structural analysis accurately and reliably. This approach not only allows for a more realistic understanding of the current condition of the building, but also helps identify intervention solutions based on compatible and reversible materials. For the same level of structural effectiveness, it is in fact possible to select solutions that ensure the static safety of the building while also being removable in the future, thus allowing the possible application of different techniques and materials. This principle is fundamental in the structural restoration of historic buildings.

In conclusion the Torre del Brandale case study demonstrates that archaeological stratigraphic analysis is not merely a historical interpretative tool but a fundamental component of structural assessment. Integrating archaeological investigation within structural diagnosis enables more reliable vulnerability assessment and supports conservation strategies based on minimum intervention, compatibility and reversibility.

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