ISCTE IUL
Instituto Universitário de Lisboa

IUL School of Social Sciences
Department of Architecture and Urbanism

Anti-seismic heritage of the late 18th century in Lisbon and in the South of Italy (Calabria). Balancing cultural values and current requirements in its rehabilitation

Stefania Stellacci

Thesis specially presented for the fulfillment of the degree of
Doctor in Architecture

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Anti-seismic heritage of the late 18th century in Lisbon and in the South of Italy (Calabria). Balancing cultural values and current requirements in its rehabilitation

ABSTRACT

A comparison of the rebuilding executed in the aftermath of two distinct earthquakes at downtown Lisbon (1755) and in Calabria region (1783) is drawn with the aim of underlining patterns of similarities and disjunctions in urban layout and construction practice.

These two urban designs arise from the same classical architectural lexicon and embody similar construction techniques, those respectively called *gaiola* and *sistema baraccato* (*cage* and *barrack system*). Employed from the second half of the 18th century onwards, both systems include the timber frame wall as a key load-bearing component.

Following a review of the archaeological findings at Herculaneum, this component becomes the golden thread of a historical journey in which the seismic event is the triggering factor of a comprehensive planning reform.

In Lisbon and in Mileto – one of several towns rebuilt *ex novo* in the south of Calabria – the architectural artefact is analysed as a cultural witness to the collective effort in reformulating time-tested local principles.

From an operational perspective, the rehabilitation of this heterogeneous and remarkable heritage is a complex task, since it is affected by different instances arising from users and property developers' interests, code-required actions, and the need to preserve the cultural significance of the building.

In this research, the question of the best rehabilitation techniques for the traditional timber frame wall is examined under a variety of criteria. This evaluation process is addressed by a multi-criteria methodology (MACBETH, *Measuring Attractiveness by a Categorical-Based Evaluation Technique*) capable of handling multiple outputs generated from qualitative expert judgments.

Key-words: Traditional timber frame walls; 18th century buildings; Post-seismic reconstructions; Rehabilitation of built heritage; Multi-criteria analysis.

Património anti-sísmico do final do século XVIII em Lisboa e no sul da Itália (Calábria). O compromisso entre os valores culturais e os requisitos atuais na sua reabilitação

RESUMO

Este trabalho analisa o património edificado após os terramotos que afectaram o centro de Lisboa (1755) e a região da Calábria (1783), com o sentido de sublinhar as analogias e dissemelhanças no modelo de planeamento e na prática de construção.

De facto, ambas as reconstruções urbanas surgem de um léxico formal de matriz clássica e técnicas de construção similares, respectivamente denominadas a *gaiola* e *sistema baraccato*, utilizadas a partir do final do século XVIII, cuja componente estrutural chave é a parede com estrutura em madeira.

A partir de uma digressão sobre os vestígios arqueológicos em Herculano, este componente torna-se o fio condutor de uma itinerário histórico onde o evento sísmico é o fator desencadeador de uma ampla reforma do planeamento.

Em Lisboa e em Mileto – uma das várias cidades reconstruídas *ex novo* na região da Calábria – o artefacto arquitectónico é analisado como um testemunho cultural de um esforço coletivo que incorpora a reformulação de princípios locais testados ao longo do tempo.

Do ponto de vista operacional, a reabilitação deste património heterogéneo pode apresentar-se como uma tarefa complexa envolvendo diferentes instâncias decorrentes dos objectivos dos detentores do património e promotores imobiliários, das exigências da legislação em vigor, e da necessidade de preservar o significado cultural do edifício.

Neste trabalho, a pertinência da tomada de decisões na conservação do património construído é discutida através da seleção da técnica mais apropriada para a reabilitação da parede mista (*frontal*), tendo em conta vários critérios em conflito. Este processo de avaliação foi abordado através de uma metodologia de análise multicritério (MACBETH, *Measuring Attractiveness by a Categorical-Based Evaluation Technique*) que permite lidar com múltiplas opções ponderadas a partir de escolhas qualitativas de especialistas.

Palavras-chave: Paredes tradicionais mistas; Edifícios do século XVIII; Reconstruções pós-sísmicas; Reabilitação de património arquitetónico; Análise multicritério.

Ai miei amati genitori

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LIST OF GENERAL ABBREVIATIONS

AML-AH – *Arquivo Municipal de Lisboa-Arquivo Histórico* (Lisbon Municipal Archive)

ANTT– *Arquivo Nacional da Torre do Tombo* (National Archive of the Tower of the Tome)

AHOP – *Arquivo Histórico do Ministério das Obras Públicas, Transportes e Telecomunicações* (Historical Archive of the Ministry of Public Works, Transport and Telecommunications)

BNN – *Biblioteca Nazionale di Napoli* (National Library of Naples)

BNP – *Biblioteca Nacional de Portugal* (National Library of Portugal)

CFRP – Carbon Fibre Reinforced Polymer

CML – *Câmara Municipal de Lisboa* (Lisbon Council)

COST – European Cooperation in the field of scientific and technical research

D.a. – *De Architectura libri decem*

DGEMN – *Direcção-Geral dos Edifícios e Monumentos Nacionais* (Authority of National Buildings and Monuments)

DGPC – *Direção-Geral do Património Cultural* (General Directorate of Cultural Heritage)

D.M.LL.PP. – *Decreto Ministeriale Lavori Pubblici* (Ministerial Decree of Public Works)

DRCLVT – *Direção Regional de Cultura de Lisboa e Vale do Tejo* (Regional Direction of Culture of Lisbon and Tagus Valley)

DRE – *Diário da República* (Portuguese Decree Law)

EBR – Externally Bonded Reinforcement

FEI – Finnish Environment Institute

FEMA – Federal Emergency Management Agency

GECoRPA – *Grémio do Património* (Association of Heritage)

GFRP – Glass Fibre Reinforced Plastic

GL – *Giornali dei lavori di Ercolano* (Herculaneum work reports)

GSE – *Giornali di Scavo di Ercolano* (Herculaneum excavation reports)

HCP – Herculaneum Conservation Project

ICOMOS – International Council of Monuments and Sites

IGM – *Istituto geografico militare* (*Military Geographical Institute)*

IMO – International Museums Office

IMPERIA – Improving Environmental Assessment by Adopting Good Practices and Tools of Multi-criteria Decision Analysis

INE – *Instituto Nacional de Estatística* (National Institute of Statistics)

ISO – International Organization for Standardization

IST – *Instituto Superior Técnico* (Higher Technical Institute of the Technical University of Lisbon)

LNEC – *Laboratório Nacional de Engenheira Civil* (National Laboratory of Civil Engineering)

L.p.a – *Livros de Posturas Antigas* (Book of Secular Positions of Lisbon)

LTV – Lower Tagus Valley

MACBETH – Measuring Attractiveness by a Categorical-Based Evaluation TecHnique

MCDA – Multi Criteria Decision Analysis

MCHA – Ministry for Cultural Heritage and Activities

M-MACBETH – software of Measuring Attractiveness by a Categorical-Based Evaluation TecHnique

MNAA – *Museu Nacional de Arte Antiga* (National museum of Ancient Art)

M_w – Moment magnitude scale

NDT – Non-destructive testing

N.h. – *Naturalis Historia*

NSM – Near Surface Mounted

OTB – *Onderzoek voor de gebouwde omgeving* (Research for the built environment)

OUV – Outstanding Universal Value

PO – *Processo de Obra* (Building dossier in Lisbon Council)

RERU – *Regime Excecional para a Reabilitação Urbana* (Exceptional Regulation for Urban Rehabilitation)

RGEU – *Regulamento Geral das Edificações Urbanas* (General Regulation of Urban Building)

SANP – *Soprintendenza speciale per i Beni archeologici di Napoli e Pompei* (Naples and Pompei heritage authority)

SCRZ – *Siculo-Calabrian Rift Zone*

TU Delft – University of Technology of Delft

UNESCO – United Nations Educational, Scientific and Cultural Organization

LIST OF ABBREVIATIONS, Chapter 5:

Sub-components of timber frame wall:

TFW – Timber frame wall

F – Framework

I – Infill

S – Surface finish

Criteria:

MC – Material compatibility

MP – Material permanence

SA – Structural authenticity

SR – Structural reliability

VTA – Visual-tactile appearance

Performance Levels (PL):

H – High

L – Low

M – Moderate

VL – Very Low

List of mathematical abbreviations

EL_p – weighted average of the evaluation level defined as 'low' under SR criterion

t_{r-s} – threshold between repair and strengthening measures

Note on the abbreviations: Other abbreviations included in *Chapter 5* are listed in the *Appendix D.2*.

Note on the quotations: In order to facilitate the reader's understanding, all quotations are translated to English in the main text and given in the original language in the footnote. In some cases, when the quotations are only reported in the footnote, the two versions, i.e. English text and original text (Italian or in Portuguese), are preceded respectively by the word "*Ita*" (for Italian) or "*Pt*" (for Portuguese).

Note on the references: References follow ISO 690: 2010(E). All references are listed according to chronological order in the footnotes.

Note on the figures: Unless otherwise specified, the figures (i.e. scheme plans, elevations, isometric views) and photographs are produced by the author of this thesis.

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INTRODUCTION

1. ON THE SIGNIFICANCE OF A RETROSPECTIVE COMPARISON OF TWO POST-RECONSTRUCTION PHASES: *POMBALINO VS BORBON*E SYSTEMS

Frequent severe earthquakes have sadly marked the chronicles of Portuguese and Italian history. Different geographical areas in the *mobile* and *noble* Italian territory[1] – from the Neapolitan area to the Apulian plain, the Emilian marshes to the eastern sicilian coastlines and Calabria Apennines – have been scarred by the cruelity of seismic forces. While the entire Italian peninsula has been struck by earthquakes with an impressive frequency and intensity[2] (approximately one every 4½ years, Mercalli scale: VIII), in Portugal, the return period is estimated as long as 150 to 200 years, and the intensity of the seismicity increases from the North toward the South, identifying the maximum seismic hazard in the mainland in the Lower Tagus Valley (LTV) region and along the Algarve coast, in the southwest region in Cape of São Vicente and the Gorringe Bank.[3]

The insight into these tragic events and the following reconstructions in the late 18th century should overshadow our contemporary scenario with a sense of impermanence: in the aftermath of many natural catastrophes, a sudden and comprehensive rethinking of the human settlements is a common response, complicated by limited economic resources. Devastating earthquakes in Portugal and to a larger extent in Italy have shown the high costs of the structural vulnerability of the historical and recent building stock.[4] To name an example, the 13th century centre of Amatrice was levelled by the 2016 earthquake which involved four regions of central Italy (6.0-6.2 M_w); in this apocalyptic scenario, the few traditional timber-framed buildings in Amatrice showed better resistance compared to the concrete buildings, as has occurred in other contexts.[5]

This comparison of *Pombalino* and *Borbone* post-disaster planning covers the lessons drawn from these experiences, analysed with a critical reading afforded by the temporal distance of these events from modern times. These historic ventures, emblematic of different approaches – *in situ* (Lisbon) *vs ex-* or *in situ* reconstructions (Calabria) – were addressed by the central authorities after overcoming the fatalistic or theodicean philosophy around natural catastrophes. Both represented crucial historical phases: beyond their national boundaries, the reconstruction

[1] This binomy evokes the title of Nimis's book*, Terre Mobili*, which sounds similar to *Terre Nobili* (Nimis, G.P. 1988).
[2] The highest seismicity is in the central-southern peninsula (e.g. Calabria Apennines and eastern Sicily), where the earthquakes occur less frequently but in greater strength, whereas other areas are more prone to earthquakes of low energy (e.g. the Alban Hills south of Rome, Vesuvius area, Etna area). This owes to complex tectonic activity: different phenomena occur simultaneously, such as the collision between the Euroasian and African plates in the north, the Tyrrhenian Basin in the west, and the subduction of the Adria micro-plate corresponding to the Apennine.
[3] (Ferrão, C.; Bezzeghoud, M; Caldeira, B.; Borges, J. F. 2016)
[4] As shown in the cluster of quakes of Friuli (1786), Irpinia (1980), Assisi (1997), Eagle (2009), Emilia Romagna (2012), Amatrice-Norcia-Visso (2016), and in Portugal, in Benavente, 40 km from Lisbon (1909) and in Azores (1980).
[5] (Langebach, R. 2007)

activities triggered broader acts of solidarity and scientific debate,[6] considerable effort that resulted in the definition of urban and construction guidance principles aimed at withstanding the effects of natural disasters.

These post-seismic reconstructions show that only the passage of time serves to bond those newly built settlements to their surroundings, which nevertheless remain incomplete in that they can never embody the history built by their communities over the centuries before their construction. Calvino states that the city is composed "of relationships between the measurements of its space and the events of its past (…). As this wave from memories flows in, the city soaks it up like a sponge and expands."[7]

Besides the difficulty of reconfiguring these relationships, it should also be noted that any proposal to plan similar construction models for other post-seismic reconstructions in an aprioristic approach would not be a successful strategy.[8] In fact, recourse to the same solutions within different socio-economic and cultural backgrounds is improper and improbable, as Nimis specifies:

> "No recipe is directly exportable due to historical-political-economic-social momentum and due to the extent of the damage, its nature, the morphology of the territory, the type of human settlement, the type of development in the place, and also the relationship to deeper factors, such as culture, traditions, and even the character of the populations whose merits and defects are suddenly laid bare, dropping any rhetorical masking."[9]

In spite of the achievement of the various goals for reconstruction, our outlook toward these historic ventures cannot abide a nostalgic reiteration today of models conceived in emergency situations, particularly because these embody top-down processes implemented by a military organization – the only possible approach in those societies based on aristocratic and polysynodal absolutism. Interestingly, as stated by Teixeira and Valla, the more centralized power is, the more rationality and geometry are affirmed in the new layout.[10]

So, if an uncritical reiteration of these planning and construction models in the future is improper, why dig up these past experiences?

Understanding the impact of these planning activities upon the local communities is unquestionably important. *Ex abrupto* hit by earthquakes – those respectively engendered along the fault lines of the Africa-Eurasia plate boundary and along the Apennine ridge – these rebuilt tissues are not a result of a gradual organic evolution. Their histories were formed through reinterpretation of their relationship with their territory and cultural memory. These

---

[6] (Keller, S.B. 1998).

[7] "[La città è fatta] di relazioni tra le misure del suo spazio e gli avvenimenti del suo passato (...). Di quest'onda che rifluisce dai ricordi la città s'imbeve come una spugna e si dilata." (Calvino, I. 1996, 18-19)

[8] In the 1965 foreword of França's book *Lisboa Pombalina e o Iluminismo*, Francastel argues that Lisbon's reconstruction cannot be viewed as a prototype or paradigm of ideal urban planning across Europe during the Enlightenment (França, J. A. 1987, 8).

[9] "Nessuna ricetta è direttamente esportabile a causa sia del momento storico-politico-economico-sociale, sia dell'entità del danno, della sua natura, della morfologia del territorio, della tipologia dell'insediamento umano, del tipo di sviluppo in atto e anche in rapporto a fattori profondi come la cultura, le tradizioni e perfino il carattere delle popolazioni di cui vengono improvvisamente messi a nudo pregi e difetti, cadendo ogni mascheramento retorico." (Nimis, G.P. 1988, 97)

[10] (Teixeira, M.C.; Valla, M. 1999, 13)

distinctive features ("tratti fondanti" in Italian) remain the basis for every future renewal or any adaptive approach. As stated by Cataldi, the critical-historical reading of the civil and territorial forms becomes "operative when, tracing the diagram of temporal development, it identifies its own typical laws of transformation".[11] Proper planning of expansion or urban renewal (under normal conditions), or in the aftermath of the natural disasters (in exceptional circumstances)[12] can take place by taking the vocations of the area and the needs of the community into account.

At the construction scale, these key principles of the 18th century timber-framed heritage are underlined: the proportion between elevation and plan of each building, the regularity of the plan and elevation development, the behaviour of the construction as a whole unit, the importance of the joints and overall ductility, and the reduction of mass compared to ordinary masonry buildings.

At the architectural scale, comparative analysis of the construction principles of this heterogenous group of buildings, with their strengths, vulnerabilities, and alterations over time, is also propaedeutic for more-durable interventions on the historical timber-framed heritage.

[11] "operante nel momento in cui, tracciato il diagramma di sviluppo temporale, ne rinviene le leggi tipiche di trasformazione". (Cataldi, G. 1974). See (Muratori, S. 1967).

[12] Venzone, the town rebuilt after the 1976 earthquake in Friuli region, epitomizes a remarkable case study of a shared and responsible management between the local community and a panel of multi-disciplinary experts. Its reconstruction, under the guidance of Caniggia and Sartogo, followed the motto: "where it was and how it was". Venzone's programme included the reconstruction by anastylosis for the main monuments, and the reconstruction by analogy for the urban fabric, by safeguarding the volumetric and typological aspects of the local buildings and by introducing new anti-seismic measures, as projected by Di Pasquale. This rebuilding was intended to be an upgrade of the ongoing process of the configuration of the human settlements (Sartogo, F. 2008).

2. AIMS AND RESEARCH QUESTIONS

This thesis is directed towards the analysis of the causal relationship between the earthquake damage in the second half of the 18th century and the response activities in Lisbon and in Calabria region. Therefore, this research integrates areas usually addressed separately in the state of art.

In order to provide broader and comprehensive insight into the post-seismic reconstruction, this research works aim to compare the historical timber-framed heritage in both contexts. Based on information collected through fieldwork and literature review, this research underlines how these seismic-resistant buildings are expressions of their respective cultural settings rooted in a common tradition and empirical knowledge gained through the trial-and-error process over the centuries.

It also strives to provide a straightforward methodology to guide decision-making related to the preservation of timber-framed heritage, using multi-storey buildings in downtown Lisbon as a case study.

This research addresses the questions:

- *What are the reasons for the prevalence of timber frame walls in Herculaneum (79AD)?*
- *What examples of anti-seismic construction preceded (and survived) the 18th century earthquakes in Lisbon and Calabria?*
- *What differences distinguish the construction systems employed after the earthquakes in Lisbon and in Calabria in the second half of the 18th century?*
- *Can a compromise be found between multiple and conflicting aims and practical solutions in current rehabilitation works?*

3. RESEARCH METHODOLOGY

A multi-disciplinary research, resulting from multiple scholarly methods and the involvement of experts in different yet complementary fields (history of traditional construction systems, chemistry, architecture, engineering), is addressed below in order to accomplish the stated aims, as explained at length in this section.

Firstly, relevant data concerning ancient and traditional timber frame walls – i.e. *craticii parietes*, *frontal*, and *parete intelaiata* – is collected through literature review and field works, which is carried out respectively in Herculaneum, Lisbon, and in Tyrrhenian area of Calabria region.

Secondly, a preliminary comparison between the cultural framework of Lisbon and of the southern provinces belonging to the Kingdom of Naples in the late of 18th century is discussed on the basis of previous research findings. However, the preliminary aim to portray accurately the architecture and construction systems of the anti-seismic buildings on a systematic basis is hampered by the discrepancy between the body of scientific knowledge related to these two contexts, as confirmed by Keller.[13] Being the Portuguese literature on post-1755 reconstruction sizeable, the selected bibliographic references are limited to those research works focused on the *Pombalino* built heritage in the Lisbon downtown and based upon archival documents and empirical evidence.[14] Some characteristics of Calabrian buildings executed after the 1783 earthquake are compared to the *Pombalino* built heritage. Previous research findings about the Calabrian post-seismic activities,[15] which was marked by the hiatus between the surveyed buildings *vs* planned urban design models, are also reviewed by the author of this thesis.

Then, the scope of research is narrowed down to two selected case studies, whose data collection comes from archival research and on-site surveys. Both case studies, a multi-storey building for renting in Lisbon and the Bishop's Palace in Mileto, are surveyed by the author of this thesis respectively in September 2014 and in March 2015. The second case study, whose historical importance and structural reliability is highlighted by Doctor Nicola Ruggieri,[16] is studied during the period of this research by the team coordinated by Professors Michele Zampilli, Francesca Geremia, and Ginevra Salerno (from University of Rome 3).[17] It should be underlined that from its survey onwards, the preservation and rehabilitation of the Bishop's Palace has been attempted by the mentioned team.

The last section of this thesis can be termed as *applied research*, i.e. aimed at finding a solution for an immediate practical problem facing the contemporary community. We refer to the impacts of the tremendous housing price growth including, but not limited to, Lisbon metropolitan area, which have been accompanied by the lack of

[13] (Keller, S.B. 1998, 150-151)
[14] (França, J. A. 1987) (Santos, V.L. 1994) (Mascarenhas, J. 1996) (Rossa, W. 2015)
[15] (Baratta, M. 1906) (Maretto, P. 1975) (Principe, I. 1976)
[16] (Ruggieri, N.; Zinno, R. 2015)
[17] (Cruz, H; Machado, A.C.; Candeias, P.X.; Ruggieri, N.; Catarino, J.M. 2016, 125-134, 135-145, 205-226)

effective application of all basic principles for the preservation of traditional architecture, customs, and local traditions by the professional system (builders and technicians). Similarly, even in absence of this such significant real estate investment, a general scarce interest in preserving the authenticity of the traditional timber-framed buildings scattered over several Calabria re-built towns can be observed over the years.[18]

The scope of the applied research focuses on a key component of Portuguese timber frame construction, the internal load-bearing wall – *frontal* – with the aim of drawing attention to the impact of specific rehabilitation techniques upon the historical buildings. Techniques for repair or strengthening the *frontal* are chosen based on an extensive survey of literature and current practice. The referenced techniques are then evaluated by a panel of experts in conservation science (i.e. chemists, architects, and timber engineers), by taking into account non-numeric and various criteria related to often conflicting values pursued by multiple-stakeholders. The research methodology selected for this evaluation process belongs to the family of *Multi-criteria Decision Analysis*: Macbeth procedure.

[18] The demolition of the 18th century *casa baraccata* in Filadelfia is referred by Tobriner (Tobriner, S. 1983). Conversely, virtuous examples of restored timber-framed buildings in Sicily are discussed in literature (Bianco, A. (ed.) 2010).

4. THESIS OUTLINE

This thesis is structured into five chapters grouped in three thematic axes corresponding to three chronological frames: the first deals with the Roman epoch (C*hapter 1*), the second examines the scenario before and after the late 18th century earthquakes (*Chapters* from *2* to *4*), and the third section addresses current rehabilitation work (*Chapter 5*).

In *Chapter 1*, the ancient treatises and Roman archaeological evidence in the Vesuvian area are briefly discussed through a literature review and on-site analysis with the aim of shedding light on the reasons for use and dissemination, construction principles, and drawbacks concerning the timber frame walls (known as *craticii parietes*).

Chapters 2&3 deal with the timber-framed heritage executed as response to impressive human losses and the large-scale building damage after the earthquakes in Lisbon (1755) and in Calabria (1783). The period preceding these catastrophes is also discussed with a twofold aim, delving into the vernacular systems and laying the basis for appropriate conservation policy.

Chapter 4 focuses on a comparison of two case studies – a multi-storey building for renting in Lisbon and the Bishop's Palace in Mileto – taking into account the urban morphology, architectural configuration, and structural principles.

Chapter 5 addresses priorities and challenges for the rehabilitation of downtown Lisbon, marked by the dichotomy between conservative and innovative instances. Finally, the research focuses on intervention techniques for the traditional timber frame wall, evaluated by a panel of experts through a multiple-criteria decision analysis method.



CHAPTER 1 – Roman timber-framed structures: ancient literature and archaeological evidence

1.1 Introduction

> "Practice is the continuous and regular exercise of employment where manual work is done with any necessary material according to the design of a drawing".[1]

The technical feature represents a qualifying and influential factor of the architectural form. The construction technique based on the assembly system may be interpreted as *trait d'union* of the craftsmen's skills and the users' requirements. Thus, the *building act* embodies a cultural expression of their own civilisation. In the preface of Adam's book, Mario Torelli specifies the importance of understanding the process that had led to a construction solution: "The shape refers to the tool, the tool to the gesture, and this to the man who execute it; similarly, the choice of a technical solution move us to find the reason that imposed it and the intelligent process that had conceived it."[2]

The importance of insightful analysis derives from these premises.

This research is focused on the timber frame walls with infill panels, which can be interpreted as a *constructive archetype*[3] that correlates *genius loci* with *genius artis* and *genius materialis*. A concurrence of several factors influenced its use and dissemination in different climatic and cultural environments. Local variations to achieve a sort of *technical hybridism* were swiftly executed without the requirement of highly skilled workers.

However, the analysis of the Roman timber framed walls may be a starting point for discussing the genesis of this construction system within the Mediterranean basin. In fact, the prehistoric discoveries near Naples (from ca. 1800 BC) bear earlier witness to this time-tested technique. Key issues shall be discussed with regards to the ancient Herculaneum, such as material characterisation, traditional tools and solutions for keeping the technique in use over the centuries. Additionally, in the case of archaeological fragments, the conditions of the findings and the current conservation measures are also briefly stated.

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[1] "Fabrica est continuata ac trita usus meditatio, quae manibus perficitur e materia cuiuscumque generis opus est ad propositum deformationis", from Vitruvius, *D.a.,* I, Chapter 1, translated by Morgan (Morgan, M.H. 1914, 5).

[2] "La forma rimanda all'arnese, l'arnese al gesto, e questo all'uomo che l'ha compiuto; allo stesso modo la scelta di una soluzione tecnica spinge a cercare il motivo che l'ha imposta e il processo intelligente che l'ha concepita." (Adam, J.P. 2004, 7)

[3] Nardi introduces this trinomial in order to explain the relationship between the technical act and the culture: "(…) The 'technical archetype', in fact, it is not just a sign, but it is also a symbol and, more precisely, is the symbol whose connection between 'meaning' and 'expression', established by a mental act, is perpetuated by the repetition of the forthcoming techniques)". *Ita*: (…)'L'archetipo tecnico' infatti non è solo un segno, ma è anche un simbolo e, più precisamente, è il simbolo la cui connessione tra 'significato' ed 'espressione', stabilita da un atto mentale, viene perpetuata dal ripetersi delle tecniche successive". The *technical acts* are thus generators of archetypes where the construction and cultural instances merged and became the essential points of building construction: "Only when they become real in the construction, the technical acts are expressions of the synthetic and the synchronic form, materials and purposes." *Ita*: "Solo nel momento in cui si inverano nella costruzione, gli atti tecnici sono espressione sintetica e sincronica di forma, materiali e fini."(Nardi, G. 2010, 123)

The selection of the ancient Herculaneum case, rather than the surrounding urban settlements (e.g. Pompeii, Stabiae, Oplontis, Boscoreale) or other geographical contexts (e.g. Cisalpine Gaul) is grounded on a twofold basis. Due to specific historical and spatial constraints, namely the population growth and the 62/63 AD post-earthquake reconstructions, the *opus craticium* was widely employed at Herculaneum. Additionally, the peculiarity of the 79 AD burial ensured the good conservation of perishable and organic components, among which many wooden findings.

In this section, a literature review retraces the historical backdrop, in which the cross-section of the bygone Roman society in the Vesuvian area has been found, preserved, and reinterpreted over the centuries.

1.2 Prolegomenon to *craticii parietes*: construction techniques in ancient literature

The traditional timber frame system was a humble technique that made use of available materials and was relatively simple to execute, not requiring specific preparation of the materials or highly skilled labour.[4] Knowledge was often handed down by master builders and craftsmen in the building practices rather than by manuals or written texts. Italian ancient literature and selected archeological findings are briefly discussed below.

1.2.1 Questions on the provenance: selected archaeological evidence

The provenance of the in-filled timber frame structure and its primary pathway of transmission represent a *vexata quaestio* in the literature: the uncertainty comes from the great number of variations of this construction technique, the multiple cross-cultural interactions that stimulated its diffusion, and the high perishability of the building materials.[5]

The majority of the walls made of wooden structures were lost after the structures had fallen into disuse. Exceptions are those rare examples in which special conditions have fostered their conservation: in the European temperate climate, in cases where the wooden elements were baked (e.g. remnants of a fire), or in specific conditions of water saturation; or in the dry climates of North and East Africa.[6]

The debate about the authorship of the *craticii parietes*[7] fits into a broader discussion related to the origin of perishable materials.[8,9] Valenzani, Augenti, and Negrelli allege the existence of an indigenous culture dormant during the Roman period, which resurfaced in times of crisis; conversely, Fronza, Brogiolo, and Valenti support a non-native origin by asserting a Germanic-Slavic provenance.[10]

Plenty of examples of timber-framed dwellings have been found from the Bronze Age; their use has been long lasting in some agrarian communities in northern Italy, to name one example. Ulrich cites the archaeological discoveries in an early Italic building from ca.1800 BC and from the Iron Age (ca.1000 BC). A grid of timber beams was filled with thin panels made with woven twigs and mud, pieces of bark and animal hides.[11]

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[4] Wooden components were preferred to other heavy materials, i.e. the extraction and processing of stone were not yet at an advanced stage. Later, in cases of the absence of suitable local stone, the use of wood and clay was also very common in the Roman provinces of Gaul (Adam, J.P. 2004, 61). Humble extra-urban constructions were made with *parietes craticiae*, as in *villae*, suburban *domus* and in urban dwellings (Durante, A.M. 2001, 110), as well as in several examples discovered in Rome dating back to the imperial period (Lugli, G. 1957) (Lasfargue, J. (ed.) 1983).

[5] (Papaccio, V. 1993, 611) (Adam, J.P. 2004, 213) (Ulrich, R.B. 2007, 98) (Laumain, X. 2013, 2242)

[6] (Bacchetta, A. 2003, 13)

[7] In this study, the term "craticii parietes" is taken to mean specifically the ancient findings, whereas "in-filled timber frame structure" or "timber frame wall" are used when the traditional components have been replaced over the centuries.

[8] Despite the term of this classification, the construction systems that included wood, vegetable fibres, straw, and raw clay achieved a structural resistance and their perishability could be overcome by the accuracy of execution (Bacchetta, A. 2003) (Antonini, A. 2014).

[9] The delay of research into the half-timbered system in Italy is very significant if compared to the studies in the Anglo-Saxon or French contexts. This gap was underlined during an international conference in Lyon in 1983 *Architectures de terre et de bois. L'habitat privé des provinces occidentales du monde romain,* where the absence of Italian participation on this debate was deemed not consistent with the construction importance of Romanic and Pre-Romanic culture (Lasfargue, J. (ed.) 1983). A subdivision and localization of the technical variants of timber frame structures starting from V century BC in the North of Italy has recently been carried out at the Polytechnic University of Milan (Gallina, M.V. 2011) (Antonini, A. 2014).

[10] (Valenzani, S. R. 2011) *apud* (Antonini, A. 2014, 19). For up-to-date references see Antonini's PhD thesis (Ibid.)

[11] (Ulrich, R.B. 2007, 91)

Based on archaeological evidence, Mariette de Vos,[12] Santoro, and other scholars also assert the autochthon provenance of this technique.

Prehistoric vestiges of timber frame walls have recently been found in the Campania region, close to Naples; these belong to the huts in Nola, preserved in the Vesuvian burial and due to the specific on-site submersion conditions in Longola (Poggiomarino, close to Neapolis)[13] (*Figure 1.01*). With regard to the first archaeological evidence, a reliable reconstruction of prehistoric huts and their dating based on radiocarbon analysis (between 1880 and 1680 BC) was made possible thanks to the negative cast formed by the submersion of pumice, ash rain, and muddy flood.[14] One type of hut is set according to an rectangular layout with two aisles. These structures are characterized by walls filled with horizontally arranged reeds between regularly spaced vertical posts which support the gabled roof together with wooden stakes inside the room.



Figure 1.01 – Reclamation made with *opus craticium* (Cicirelli, C.; Livadie, C.A. 2007, 481, 485)

With respect to the latter case, a proto-historic settlement in Longola di Poggiomarino, approximately ten kilometers East of Pompeii within the perifluvial wetland, was discovered in 2000. This riverside village is dated

[12] Mariette de Vos lists three earthen construction typologies belonging to the Italic-Etruscan world: (i) *lateres crudi* (cited by Vitruvius in *De Architectura libri decem* 2,3); (ii) *parietes formacei* (cited by Pliny the Elder in *Naturalis Historia* 35,48); and (iii) *parietes craticii* (De Vos, M.; Ciotola, A.; Allavena, L. 1992).
[13] (Cicirelli, C.; Livadie, C.A. 2007)
[14] (Livadie, C.A. 2001) (Bianchini, M. 2010, 14-15)

from the Iron Age to the beginning of the 6th century, when the population left the village for two newly built centers: Pompeii and Nuceria. Fishermen had lived in modest half-timbered dwellings[15] near the river Sarno since prehistoric times, in small islands and reinforced by piling. These islands suffered cyclical changes inherent to the specific hydrogeological site. Land reclamations were periodically executed by overlapping timber frame walls repurposed from disused huts. [16] The impressively good conservation of the archaeological findings (about 5000 artefacts), especially of the oak structural elements, resulted from the conditions of on-site submersion into wet earth.

By contrast, several authors attest the origins of this technique from eastern longitudes,[17] namely in Asia Minor (e.g. Turkey[18], Brousse), where medieval timber framed buildings have been found in large number.[19] In fact, these medieval dwellings embody a proto-historic practical tradition based on the combination of wood with other available materials. These could bear witness to a consolidated and autochthon construction culture that was most likely transmitted via the Balkans to Central Europe. Adam states that several types of joints employed in the Roman construction systems came from naval carpenters of the Greek Age.[20] Indeed, the influence of Greek culture in Herculaneum was relevant because of the attribution of its foundation as a coastal rampart by Dionysius of Halicarnassus. Unlike in the Roman context, the continuity of the structural use of wood in Greece and Turkey had been maintained due to the specific awareness of its anti-seismic performance.

Regardless of the debate on the origin of this timber framework, the fundamental role of the Romans for its dissemination within several regional contexts is unanimously assumed.[21] The Romans spread this mixed construction system[22] throughout Gaul to the provinces of their jurisdiction, implementing the non-indigenous construction experience with their distinctively pragmatic, shrewd, and standardized work in order to increase the rapidity of construction.[23]

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[15] Five different rectangular huts have been found, as catalogued: apsidal single aisle, divided by different rooms (type 1), apsidal with two aisles (type 2), with a single nave (type 3), with three (type 4) or four aisles (type 5) (Livadie, et al. 2010, 547-548).

[16] Two reclamation techniques were employed during the early Iron Age to gradually remove the water from the ground. The first was the channelling of surface waters into secondary ducts in order to lower the water table; the second system was the backfilling technique by periodic elevations of the ground surface. This latter system relied on structures made of heterogeneous material with the aim of compressing the soil. This infill consisted essentially of wooden elements and other disused materials in formworks made from timber planks and stakes in the sand layer (Cicirelli, C.; Livadie, C.A. 2007, 477).

[17] The use of a timber skeleton as a reinforcement of the masonry stone is documented at the beginning of the II millennium BC, with different arrangements, in a wide area between Mesopotamia, Egypt, the Mycenaean area, and Anatolia.

[18] The Turkish traditional wooden buildings could be classified by the type of wall structure: (i) *hatil* and *hımış*, as timber-laced masonry; and (ii) *hımış*, *dizeme,* and *bağdadi*, as timber-framed buildings. Doğangün analyses the different seismic resistance based on the presence (or not) of bracing components (Doğangün, et al. 2006).

[19] (Papaccio, V. 1993, 610)

[20] (Adam, J.P. 2004, 103-104)

[21] During the Augustan period, Rome appears to have been a vertically-developed metropolis, a sort of showcase of a large number of architectural forms and construction techniques, most of which were made of wood or *opus craticium* (Gros, P. (ed.) 1997, 193). Buildings coated with *opus caementicium* in adobe and tufaceous materials were also very common.

[22] Roman building techniques included the combination of different materials and also the execution of structural weft, such as *opus mixtum* and *opus reticultatum*, *opus africanum*, *opus craticium*, *opus velinum,* and *opus vittatum* on the facade of the ground floor (Papaccio, V. 1993, 612).

[23] As evidence of their exceptional technical skill, Gallina cites temporary bridges (*pontes tumultuarii*) that Romans were able to build in as little as one day during their military operations (Gallina, M.V. 2011, 25-26).

1.2.2 Vitruvius's treatise and Latin sources: the significance of the written witnesses

De Architectura libri decem, written approximately between 35 BC and 25 BC, is unanimously considered the essential reference *corpus* of the ancient times and the fundamental source for the transmission of Roman construction knowledge.

However, *De Architectura* does not provide any drawings or details – although it is assumed that they were included in the original version –[24] and encompasses a limited historical period. Vitruvius's attempts to organize the technical knowledge related to the architectural doctrine are limited, as can be understood from the discrepancy existing between the contents of the treatise and the types of construction actually employed during the period of his writing. The author avoids describing the contemporary building renewal of the Augustan Principate. According to Tafuri, Vitruvius's treatise is "a reprocessed discussion after a concluded fight".[25] Vitruvius could be interpreted as an agent of the *power* in the sense that the author depended on the *power* of the Roman Empire, and the architecture itself was a direct expression of that *power*.

Moreover, low importance is attributed to timber framework construction in this treatise. Conversely, as regards the other construction techniques, Vitruvius's indications are very detailed in terms of terminology, compositions, and operation methods. Thus, the dichotomy between the treatise and the contemporary building practices can be easily observed as regards this type of walls, which occupies a non-marginal place in the Roman technical culture.

The *craticii parietes* is the last method of building walls described in *De Architectura* (Book II, Chapter VIII), emphasing its drawbacks derived from physical weakness (i.e. cracking at the interface between the timber framework and the infill), fire hazard, and susceptibility to moisture.[26]

Vitruvius first provides a little information on the geometry, assembly of the elements (IV, 23), wooden species (II), type of infill (II, 9, 17; V, 2, 2; IV, 4, 1; VI, 3, 9, 7), and surface finish (VII, 3, 34-40). This is followed by a discussion of drawbacks and advantages. [27]

The structure of the wall consists of a timber skeleton on a stone or brick plinth, and of vertical uprights (*arectaria*) and horizontal members (*transversaria*). For the execution of the framework Vitruvius recommends the

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[24] This treatise was known to medieval scholars and transmitted through the Carolingian copyists (Krinsky, C. H. 1967) and rediscovered by Bracciolini and Cencio in 1414. During the 16th century *De Architectura* was republished by friar Giovanni Giocondo (Florence, 1513) and by Cesare Cesariano (Como, 1521): both versions included remarkable depictions with useful captions, unlike Vitruvius's original Latin treatise. In particular, Cesariano's treatise refers to timber constructions built by Asian populations (Rovetta, A. (ed.) 2002). Later, another edition, translated and commented on by Daniele Barbaro (1556), was enriched by the drawings executed by Andrea Palladio. The researcher Antonini also refers to Giovanantonio Rusconi's treatise (1590) that included illustrations of "extraordinary realism" which more closely resemble the manuals of the 17th century rather than the Renaissance treatises (Antonini, A. 2014, 41-47). The detailed drawings should suggest that Rusconi had directly observed contemporary wooden artefacts from the North of Europe (e.g. Moscov).

[25] "la messa in discorso di una battaglia conclusa". (Tafuri, M. 1984, 41). Choay also underlines the absence of a critical approach in Vitruvius's work (Choay, F. 1986, 162).

[26] "Craticii vero velim quidem ne inventi essent; quantum enim cleritate et loci laxamento prosunt, tanto maiori et communi sunt calamitati, quod ad incendia uti faces sunt parati" (*D.a.* II, 8, 20).

[27] "As for 'wattle and daub' I could wish that it had never been invented. The more it saves in time and gains in space, the greater and the more general is the disaster that it may cause; for it is made to catch fire, like torches. It seems better, therefore, to spend on walls of burnt brick, and be at expense, than to save with 'wattle and daub', and be in danger. And, in the stucco covering, too, it makes cracks from the inside by the arrangement of its studs and girts. For these swell with moisture as they are daubed, and then contract as they dry, and, by their shrinking, cause the solid stucco to split. But since some are obliged to use it either to save time or money, or for partitions on an unsupported span, the proper method of construction is as follows (...)".(Morgan, M.H. 1914, 57-58)

Abies alba (silver fir) due to its strength, the high reach of the tree,[28] its lightness, and its workability (*D.a.* 2, 8-9, 11-12).

As regards the plaster finish, Vitruvius recommends two solutions. Firstly, a composite system made of a layer of clay mortar, a row of horizontal rods fixed by nails with wide heads (*claves muscarii*), a second layer of clay mortar and, finally, a row of vertically arranged rods (as displayed by Galiani, *Figure 1.02*). A double layer of reeds is placed in alternating directions with mud mortar to cover each of the mats, presenting technical advantages such as biaxial compressive strength and greater compactness which would prevent the layers from crumbling. This solution may have been fairly demanding in terms of cost and effort,[29] and it implied a certain thickness.

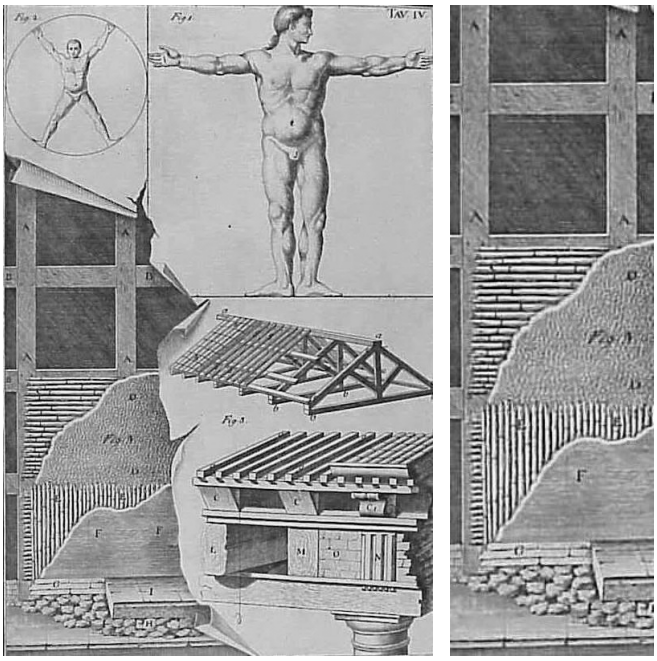

Figure 1.02 – *The human proportions: sections of walls and roofs*, plate no. iv (1758) in Vitruvius's treatise edition by Galiani and detail of timber framework and double layer reeds

An alternative solution for the coating did not employ any such grid; the *craticii* walls would be protected by a lime-aggregate mixture (*opus tectorium*), in three or four layers, increasingly thin and fluid: the last one, finer and white-coloured, was called *opus albarium*[30] (*D.a*. VII, 3-4,11) and was made with lime and gypsum.[31]

[28] Until 30 meters (*D.a.* XVI, 18-19).

[29] The mismatch existing between Vitruvius's recommendations and the practice in the work site can be also observed both in the use of timber frame walls and of plaster on other surfaces. In fact, Vitruvius recommends seven layers (reduced to five by Plynius), but the common ancient plaster was generally made just of three layers (Bettini, S. 2001, 84). Another example of a simplified version of Vitruvius's recommendations: the wooden frames that were nailed on both sides with mats of entire reeds (so-called *ingargiolato di canne*) being replaced in practice by crushed and twisted reeds and leaving the internal space empty.

[30] In the ancient worksite, the builders who executed the *opus albarium* or *gypsum* were denominated *albarii* and *gypsarii*, according to the Latin custom of attributing the name of material components to the craft when the material had an intrinsic, defining influence on the activity, whereas in other cases the term indicating the work simply came from the action itself (e.g. *pictor*). As regards the term indicating the finish surface, *opus albarium* (from *album* meaning white), Vitruvius is the first researcher who mentions this technique (Bettini, S. 2001, 81).

[31] In cases of external finish over *opus craticium*, gypsum was not recommended due to its water solubility. Vitruvius's technical recommendations may be interpreted as a corrective measure to an excessive use of gypsum in this period (Bettini, S. 2001, 82).

References to the use of clay mortar for the preparatory layer can be found in the ancient literature (Plinius, *N. H.*, XXXV, 169; Vitruvius*, D.a*. VII, 3, 11).

The composition of this plaster was highly variable and could include wet soil or clay that could in turn be tempered with animal dung, straw, or sand. This second solution was less efficient but most common than the first, as stated by Maiuri.[32]

The two above-mentioned construction measures for wall coating are suggested by Vitruvius in order to prevent the crumbling of the surface finish caused by the difference of the thermal capacity and hygroscopicity of the wood and the infill.

The most important advantages relating to this construction system is that enables a fast construction and is a space-timing solution,[33] whereas its drawbacks are the rising damp and the high ignitability. To prevent the first cause of decay, Vitruvius recommends the execution of stone foundations: "solum substruatur alte, ut sint intacti [parietes] ab rudere et pavimento"(*D.a.* II, 8, 77).

Following a brief diachronic literature analysis, it may be observed that several authors describe or cite this construction system (*Appendix A.1*).

Vitruvius mentions the *craticii parietes* or the adjective *craticius* (with a plural name in *D.a.* II, 8, 20); Pliny the Elder mentions it in the 1st century AD (*Etym*, XIX, 10, 16); and lastly, Saint Isidore of Seville refers to the *cratis parietum* in the 6th-7th centuries (XXXV, 48). Similarly, in the 4th century AD Palladius cites the *craticiis podis* (I, 19,2) that was employed for granaries in farm buildings. Finally, Sextus Pompeius Festus (later 2nd century AD) indicates the weakness of the upper levels of dwellings made with this technique.

As evidence of the diffusion of the *opus craticium* within Roman residential settlements during the Republican era, it is worth mentioning an extract from *Historiae Adversus Paganos* by Paulus Orosius (V, 12.8). During the riots in 121 BC, the *craticii parietes* belonging to the house of Fulvius Flaccus were completely breached, as reported in the account with the Latin expression "rescisso pariete".[34]

Additional information can also be gleaned from other sources, e.g. epigraphs, proverbs, satirical books, and legislative texts. The image gathered from these sources depicts the Roman construction technique with almost pejorative connotations in terms of structural performance. However, in some cases, the timber framework could bear significant weight, as can be deduced from the statement of the jurist Ulpiano in *Digesta* (XVII, 2, 52.13) in which a wall structure separating two dwellings belonging to different owners allowed the possibility of adding a roof structure and even an extra-floor.[35]

Oddly enough, even if this mixed technique was quite widespread in the Roman Empire, it came to be omitted by later treatise writers such as Leon Battista Alberti. Alberti only mentions the *opus craticium* with the

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[32] (Maiuri, A. 1958, 409, 412)

[33] "quantum enim cleritate et loci laxamento prosunt (...). Sed quoniam nonnullos celeritas aut inopia aut in pendenti loco dissaeptio cogit, sic erit faciundum." (*D.a.* II, 8, 20)

[34] Mentioned by Bacchetta (Bacchetta, A. 2003, 122): "Duo Flacci pater filiusque cum per aedem Lumae in privatam domum desiluissent foresque obiecissent, rescisso craticio pariet econfossi sunt." (*Historiae Adversus Paganos*, V, 12.8)

[35] "item Mela scribit, si vicini semipedes inter se contulerunt, ut ibi craticium parietem inter se aedificarent ad onera utriusque sustinenda deinde aedification pariete alter in euminmitti non patiatur, pro socio agendum". However, the validity of this statement should be measured with caution, given its contextual purpose serving one side of a legal argument. As regards the interpretation and the transmission of knowledge in Roman legal texts, see Saliou (Saliou, C. 1994).

same adverse judgment of Vitruvius by condemning it and associating its use to the Roman plebs. However, the low interest in the technique is consistent with the sycophantic approach of the author towards Vitruvius's treatise.

Key questions arise from the re-editions of *De Architectura* in the late 18th century: *was the republication of the treatise influenced by the Vesuvian discoveries? What influence did this republication have on contemporary construction practices, particularly in the Calabria reconstruction carried out under the Neapolitan Kingdom?*

These two questions arise from the historical fact that in the same chronological period (late 17th century), the technicians belonging to the *Borbone* court engaged in two ambitious and complex programs without historical precedent: only fifty years elapsed between the excavation at Herculaneum and the post-earthquake reconstructions in the Calabria region.

These questions suggest two research paths. The first would be based on a comparison of the re-publications of Vitruvius's treatise from before the second half of the 18th century with those that came after. The second would entail attentive analysis of archival material (reports, drawings, descriptions of wooden findings) related to underground excavation.

Ruggieri perceives the impact of La Vega's discoveries and the construction solutions employed within his rebuilt programme in the Calabria region. In particular, the author provides some analogies between the recommendations of Vitruvius and the external walls of the 18th century Bishop's Palace in Mileto (Vv) in the Calabria region.[36] However, no evidence (e.g. reports, letters, drawings) proves a direct relationship between archaeological discoveries of timber framework at Herculaneum and the conception of the anti-seismic structural system employed in the Calabria region.

In addition, the re-editions of Vitruvius' treatise during the 18th century do not introduce anything new related to the Herculaneum discoveries, despite suddenly expanding the horizon of knowledge on the *modus vivendi* and *operandi* of Roman society. After several editions of *De Architectura* during the 16th century,[37] Marquis Berardo Galiani published two versions of Vitruvius's treatise in Naples in 1758 and in 1790.[38] In particular, Vagnetti states that the reason for the 1790 publication would have been related to the Roman seaside discoveries.[39] The fact that the Marquis Galiani himself had belonged to the *Academia Ercolanese* suggests an innovative approach of the author towards Vitruvius's source following the Herculaneum discoveries.

Nevertheless, Galiani does not mention the coeval discoveries in the preface or within the text, with the exception of Paestum. As underlined by Pierattini, the primary aim of this re-edition would have been simply to provide a reliable text with complete philological notes and also to update the language that had become obsolete.

If a direct cultural continuity is not easily defensible between Herculaneum findings and the Calabrian anti-seismic system, a proper comparison between the Roman technique and the *Borbone* system cannot ignore the material similarities and analogous construction principles, e.g. the reduction in the weight from the lower to the upper floors and the ductile behaviour.

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[36] The Bishop's Palace of Mileto is thoroughly discussed in *Chapter 4*. See (Ruggieri, N. 2013, 5-6).

[37] See footnote 24

[38] Galiani's text was published in seven editions. Here the 1790 version is referred to, which is preceded by a preface by Pierattini and includes some drawings from the treatises published from the 16th to 19th centuries. This edition does not include the Latin text, unlike the 1758 one (Galiani, B. 2005).

[39] "the commitment devoted to this new translation and to his commentary (...) must be put in relation with the new and remarkable archaeological interests that were rapidly spreading in Europe following the writings of Winckelmann, interests that (...) had found fertile ground to propagate and succeed precisely in the Neapolitan region". (Vagnetti, L. 1978, 119)

1.2.3 Semantic and syntactic questions in ancient literature

The significance of the ancient literature on the woodworking, whose analysis should start from its nomenclature, is self-evident and unquestionable. Ulrich specifies that most questions related to the Latin nomenclature (e.g. type of joints, tools, description of components) result from the absence of ancient treatises on woodworking. In addition, the texts that have survived were written by non-specialists.[40] Laumain asserts the absence of a specific nomenclature in the Roman vocabulary related to the timber frame system, as compared to the ancient Greek vocabulary, but this semantic difference doesn't necessarily reflect a disparity in the use between the two societies, but could be simply interpreted as an indicator of "disdain or how unnecessary [it] was for Romans to have an ad hoc vocabulary".[41]

Within the considerable literature on the Roman construction techniques, an essential overview based on the operative process was addressed by Lugli in 1957 and by Adam in 1984.[42] More recently, Giuliani re-examines these materials with a technological perspective: the author strives to overcome the risk of historical-archaeological simplifications through an accurate investigation in terms of metrological, material, and structural features, as appreciated by Bacchetta.[43] In addition, Ulrich provides a clear overview of the ancient sources and of the main questions surrounding the woodworking tools, examining recent discoveries within the Roman Empire in the Italian provinces (e.g. Lavinium) and in Britain (e.g. Verulamium).[44]

This cross-cutting approach to perishable materials issues took place in contrast to the previous mainstream approach, which was focused on the central Italian area without considering the suburban settlements. Bacchetta also widens the field of interest by choosing a technical-functional research methodology instead of a stylistic-comparative approach. In particular, the author refers to extensive bibliographic references that reflect the increasing interest on this topic[45] and the resulting improvement of technologies employed during stratigraphic analysis.[46]

In relation to etymology, the term *opus*[47] *craticium* is a modern denomination introduced by Lugli,[48] probably referring to the archaeological evidence brought to light in the Pompeii and Herculaneum sites.[49]

Bacchetta lists the Latin written sources belonging to the Roman Age, with interpretation keys provided for each (*Appendix A.1*). Lugli cites Vitruvius: before 117-121 BC, prior to the construction of the Temples of *Concordia* and of *Castori* in the Roman forum, brick walls were very common,[50] although their execution implied a waste of space due to their large thickness. In fact, these walls could reach up to 44.4 cm (one and half Roman

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[40] (Ulrich, R.B. 2007, 61)
[41] (Laumain, X.; Sabater, A.L. 2012, 1214)
[42] (Lugli, G. 1957). In regard to Adam's book, "*La Construction romaine: Matériaux et technique"* (1984) was translated from into English and Italian ten years later and then republished (Adam, J.P. 2004).
[43] (Giuliani, C.F. 1990) (Bacchetta, A. 2003, 9)
[44] (Ulrich, R.B. 2007, 97)
[45] As noticed by Ulrich, the majority of the research attention has been focused upon Roman masonry and *concrete* constructions and their various facings (Ulrich, R.B. 2007).
[46] (Bacchetta, A. 2003)
[47] Lugli illustrates the difference between *opus* and *structura* according to Vitruvius' use. In the case of vertical structures, *opus* is a complex work including the wall, the inner core and the external face. *Structura* means the nucleus of the wall and the type of connection to the external wall, that it could be made with the same components (e.g. *structurae latericia* and *testacea*) or with different materials (e.g. *structura caementicia*). In Italian *craticium* is translated *graticcio*.
[48] (Lugli, G. 1957, 34)
[49] (Bacchetta, A. 2003, 124)
[50] (Franceschini, M. 1998, 757)

foot, so-called *cubitus*) or 59.3 cm (two Roman foots, so-called *pedes*).[51] Thus, in order to save space, a timber skeleton filled with clay made decreases in weight and thickness possible, and for these reasons it was progressively preferred to previous techniques.[52] As stated by Wallace-Hadrill, this technique corresponds to the English *wattle and daub* technique, employed for the execution of flimsy partitions.[53]

It is relevant to underline that the mixed technique comprising the clay-filled timber skeleton was mentioned by the term *crates* in the ancient literature and never joined with the term *opus*, for example by Plynius "illini (…) crates parietum" (*N.h.* XXXV, 48) with the reference to the coating of the surface of the wall by mud, or in the famous adverse comment Vitruvius included in *De Architectura* (II, 8, 20) (*Appendix A.1*).

After Lugli's publication, the locution *opus craticium* was incorrectly used in the extensive literature by referring to it as having been introduced by Vitruvius or attested by ancient literature sources. In addition to this linguistic impropriety, the polysemy of this term is another aspect that should not be neglected. One of the most common misunderstandings regards the use of the term *opus craticium* in place of *torchis*, meaning imprint of reeds in plaster (Italian: *incannucciato*).[54]

More than syntactic, this is a semantic question: the *corpus documentarii* on construction techniques should be interpreted not only as aiming to a documentation and dissemination of the construction system; it should also be recognized as a balancing between the material and the functional significance. Similarly to the etymology of *balloon frame* that reminds the lightness and temporariness of a construction system, the genitive *craticii* keeps in mind the light filler and thus a fragile and no durable structures, such as the trellis made with marsh reeds or sprigs linked with ropes.

Probably from the original use of intertwined vegetable to infill each frame, this term was extended to indicate also the load bearing structure, namely the timber skeleton.[55]

[51] The metrology system is based on the human body: "Homo omnium rerum mensura est". Roman *pes*, whose sample so-called *pes monetalis* was guarded in the temple of Juno in Capitoline Hill (*aedes Iunonis Monetae*) correspondes to 29.65 centimeters. This misure unity is slightly higher than the Osco-Italic *pe*s that mesured 27.5 cm.

[52] (Lugli, G. 1957, 44-45)

[53] Wallace-Hadrill also refers to the common use of this tecnique for making sheep pens (Wallace-Hadrill, A. 2011, 262).

[54] (Bacchetta, A. 2003, 127) (Laumain, X.; Sabater, A.L. 2012, 1214) (Antonini, A. 2014, 6)

[55] (De Vos, M.; Ciotola, A.; Allavena, L. 1992, 52) (Wallace-Hadrill, A. 2011, 262)

1.3 Urban stratigraphy at Herculaneum: challenges and potential for survey campaigns

The scarcity of references (or drawings) in the ancient literature and the high perishability of the raw materials impede a comprehensive understanding of the ancient timber-framed system. For many years knowledge of it had relied on the Roman *ville souterraine* with the buried towns expected to exemplify the image handed down by Vitruvius's treatise.[56] However, Maiuri underlines the opportunity to gain further insight from the discoveries at these mid-sized towns, which go beyond the written sources:

> "Already the private buildings of Pompeii show that the anomalies are much more frequent than the regulations would have permitted, and that the iron law of space and the crisis of urbanism explain peculiarities and construction/architectural deviations better than the manuals of antiquities and architecture".[57]

1.3.1 Unlocking the reasons for the relevant presence of wooden findings

The archaeological excavations embody a significance that cannot be deemed as circumstantial in historical and logistical terms. Vesuvian findings have raised questions and unexpected research paths and have evolved into an international programme, beyond the wherewithal of the Institutions for the Safeguarding and Management of this area (*Soprintendenza Archeologica di Pompei e Ercolano*).[58] Interest in this archaeological evidence has fostered the continuous improvement of research methodology from the 18th century until the present, with relevance for classical studies, anthropology, and the science of volcanology.

However, the archaeological work in Vesuvian towns represents a discontinuous, controversial, and still ongoing process: relevant shortcomings of the current findings can be underlined. Environmental constraints, such as the location (subsoil), the orography (low water table) and the cadastral state (requiring long and costly land expropriation), as well as operational factors (the different excavation methodologies and the discontinuous pace of the works) have imposed significant difficulties for gathering and understanding the archaeological findings at Herculaneum. In addition, as noted more than one hundred years ago by Ruggiero, the intensive urbanization of the surrounding settlement has represented another strong unfavourable constraint. The uncontrolled settlements on the upper levels, initially called Resina,[59] (*Figure 1.03*) have always been a crucial obstacle to the excavations, as noted in a description of work done in the late 17th century:

> "Initially, it did not seem possible to expose any part of the ancient town due to the immense height of land that covered it and the many modern houses that were built on top, so the excavators were forced to wander blindly in caves and tunnels, drilling

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[56] (Adam, J.P. 2004, 7)

[57] "Già l'edilizia privata di Pompei mostra che le anomalie sono assai più frequenti che la regola non ammetta, e che la ferrea legge dello spazio e la crisi dell'urbanesimo ci spiegano singolarità e deviazioni costruttive ed architettoniche assai meglio dei manuali di antichità e di architettura". (Maiuri, A. 1964, 22)

[58] The Italian cultural monopoly of these discoveries had been in place since the Italian Parliament's rejection of Waldstein's proposal for finance and support in 1905-1907 (Maiuri, A. 1958, 6) (De Carolis, E. 1998, 47) (Catalano, V. 2002, 60). However, recent policy has been opening up to international financial support and to inclusion of a multi-disciplinary research team (see footnote 125).

[59] This toponymy immediately suggests the distinction of the two centres (Herculaneum and Resina). The change of name from *Resina* to *Herculaneum* was approved by the Decree Law of the President of the Republic on February 1969, no. 40 (De Simone, A. 2007, 72, 80).

through walls and mercilessly stripping the buildings of more than could be carried – not only things of value but also of completely useless material". [60]

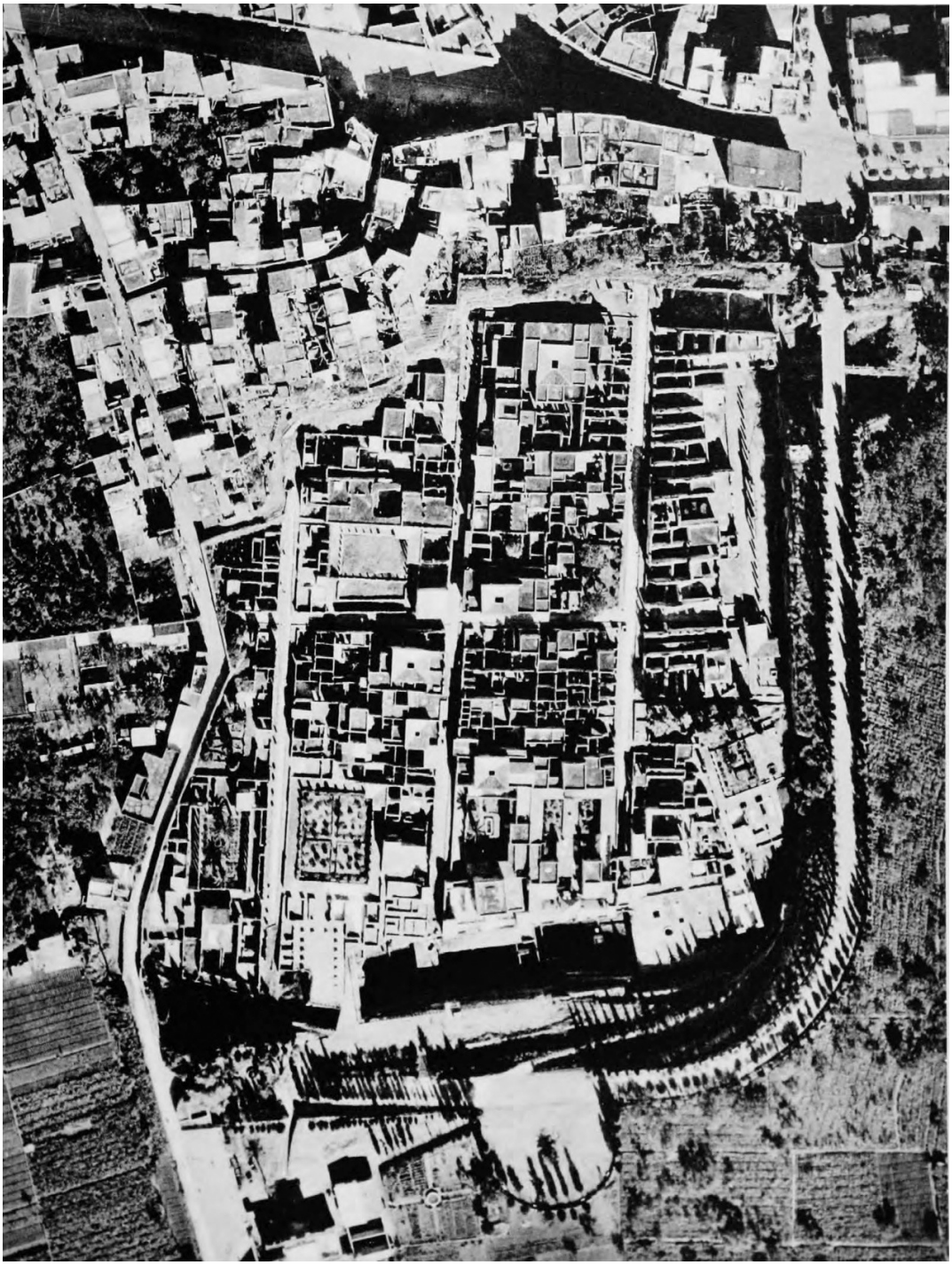

Figure 1.03 – Aerial view of Herculaneum site and the adjacent Resina (Maiuri, A. 1958, 19)

[60] "Non parve dapprima possibile il mettere allo scoperto nessuna parte dell'antica Città per la sterminata altezza delle terre che la coprivano, e per le molte case moderne che vi erano edificate sopra, onde fu forza andar vagando alla cieca per grotte e per cuniculi, forando muri e spogliando senza misericordia gli edifizi di quanto se ne poteva levare non solo delle cose di qualche valore ma fino ai materiali affatto inutili". (Ruggiero, M. 1885, XIII)

The inconsistency of the current urban landscape of Herculaneum lies in the unresolved dichotomy between the ancient town buried by the *Plinian eruption*[61] and the urban tissue that covers a large part of the unexcavated area on the upper level.

Regardless of these adverse factors, Herculaneum is an unparalleled context for a deep understanding of the traditional timber-framed system, whose wider diffusion in this mid-sized town compared to other Roman settlements (e.g. Pompeii, Stabiae, Oplontis, Boscoreale) may have resulted from two factors: (i) widespread use in the Roman intervention works, especially after the 62/63 AD earthquake; and (ii) excellent preservation of the timber components due to pyroclastic casting from the 79 AD eruption.

During the Roman Republic, masonry structures were preferred for their durability and structural strength. On the other hand, being a very dynamic town under a population pressure, Herculaneum was often subject to alterations, which applied new construction solutions and composition scheme. Acceleration of this building dynamism was spurred by the damage caused by the frequent quakes, especially that of 62/63 AD. In fact, the reconstruction involved structural changes to the original building lots (e.g. enlargements, mergers, demolitions), within several tenements in Pompeii and Herculaneum employing mixed construction techniques.[62]

In Herculaneum the extension of the interior living space by building additional floors or overhanging structures was common and more viable than other solutions due to the restricted layout of the *insulae* (grid of rectangular blocks) during the 2nd and early 1st centuries BC period. In fact, extension of the living space was not allowed on the ground floor in the rear or in contiguous open land, unlike what happened in the row houses of *Regio I* and *II* at Pompeii.[63]

Thus, the traditional type of Italic *domus* underwent significant alterations due to the introduction of new levels[64] and the fragmentation of the internal space due to lighting needs and the desire for more spatial flexibility, with multiple families taking up residence inside the same dwelling and the consequence of redefining the boundaries of intimacy between them.[65] The population growth and the need for fast and low-priced structures spurred an upgrade of construction methods, such as the preference for the trellis frame during the Roman expansion. The verticality of the structures[66,67] was likely related to the demands of private citizens especially belonging to the merchant class and may have been initiated because of the ambition to open commercial space in a more lively urban area, near the Forum. This area corresponds exactly to the Herculaneum archaeological site brought to light so far.[68]

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[61] The term is drawn from Plinius Caecilus Secundis, so-called *Plynius the Elder*, unlucky witness and great scholar of Vesuvius eruption (Carolis, E.; Patricelli, G. 2003, 8). Dead because of sulphurous exhalations, Plynius describes this natural disaster: "Interim e Vesuvio monte plurimus locis latissime flammae altaque incendia relucebant, quorum fulgor et claritas tenebris noctis excitabatur (…). Iam cinis, adhuc tamen rarus, respicio: densa caligo tergis imminebat, quae nos torrentis modo infusa terrae sequebatur (…) audiere ululates feminarum, infantus quiritatus, clamores virodorum (…)"(Epistulae IV, 16, 20).

[62] (Spinazzola 1953, 257-281) (Papaccio, V. 1993, 610)

[63] (Andrews, J.N. 2006, vol.1, 170)

[64] An insightful analysis of the upper floors of apartment residences at Herculaneum and Pompeii is provided by Andrews in his PhD thesis (Andrews, J.N. 2006).

[65] (Clarke, J. 1991) (Anguissola, A. 2012, 152-159)

[66] Catalano notes that in many cases the houses of the reconstruction reached just half the height of the previous blocks at Herculaneum (Catalano, V. 2002, 19).

[67] "It has been pointed out that in the more conservative, provincial town of Pompeii only balconies employ construction in *opus craticium*, whereas Herculaneum, near the great city of Naples, more accurately reflects current experimentation". (Clarke, J. 1991, 262)

[68] (Catalano, V. 2002, 19, 23)

Despite the modest yet regular urban layout, Herculaneum was more prone to experimentations and influenced by nearby Naples for cultural, economic, and technical reasons.[69] During the post-earthquake reconstruction, the *opus latericium* or *testaceum*, *opus incertum,* and *opus reticulatum* were preferred for cost-reduction since they involved the re-use of materials from damaged or destroyed constructions. Additionally, these Roman mixed systems for reinforcement allowed for making structural connections through *opus testaceum* or *opus vittatum*, usually arranged in narrow rows. Isolated elements (e.g. columns) were reinforced (had their gaps sealed with lead), or were strengthened by buttresses. Several features, such as joints, overhangs, masonry recoveries, and cracks and detachments within arcades and peristyles, can be attributed to the Augustan Period and the series of quakes between 62/63 AD and the burial in 79 AD.[70]

Evidence of upper floor decorations (*insulae* III-IV, Insula Orientalis II) provides an insight into the original domestic environment, whose features would not have differed much from those of the ground floor.[71] The interior space was split into small units by the execution of this type of walls. Traces of paintings and the valuable furniture discovered in these units suggest that the landlords were somewhat wealthy and therefore not constrained to using timber frame walls for economic reasons. It may be supposed that the main reason for the large use of timber frame walls in Herculaneum was for their comparatively light weight, to avoid placing loads on sites not directly supported by walls below. They were therefore free to divide the apartments without any structural concerns or physical constraints, as also argued by Andrews.[72]

Turning to the second factor for the abundance of timber frame walls at Herculaneum, it should be noted that the conservation of timber structures and furnishings, e.g. flights of staircases, bedsteads, clothes cabinets, cupboards, and the windlass with original rope depended on the characteristics of the pyroclastic events associated with the eruption (*Figure 1.04*). The eruption of Vesuvius in 79 AD buried a broad ellipsoidal area on the south-eastern slopes of the volcano and released a hot, swift-moving mixture of volcanic glasses and ash (*tephra*).[73] It should be noted that the burial circumstances were quite different in the two Roman seaside towns.

In Pompeii, the highest parts of the buildings were totally or partially destroyed during the rain of ashes that formed 6-7 meter-high stratified layers. Additionally, atmospheric agents passed between the alternate layers of lapilli (white pumice) and ashes, and thus prevented the conservation of the ancient materials. At Herculaneum, a devastating flood pushed the coastline back by a half kilometre. A hard tuff bank buried the town, preserving the ancient urban plan, the settlement structures, and even the perishable furnishings.[74]

Herculaneum was overwhelmed and submerged by flows of volcanic material at a very high temperature (400ºC), which carbonised the organic components, sealing them in an anoxic environment and providing unique conservation conditions. In particular, the temperature reached by the soil caused the carbonisation of organic materials, e.g. wood, cloth, foodstuffs, and papyrus (*Figure 1.04*).

Unfortunately, many of the carbonised wooden artefacts have not been maintained. The fragility of the

[69] (Clarke, J. 1991, 262) (Catalano, V. 2002, 18)
[70] (Papaccio, V. 1993, 609-610)
[71] (Andrews, J.N. 2006, vol.1, 100-101)
[72] Ibid.
[73] The chronology of the volcanic eruption is well known by historical sources, as mentioned by the archaeologist and ethnographer Andrea de Jorio in his preface (e.g. Lucius Annaeus Seneca minor, Cassius Dio, Strabo, Plynius) and the geological dataset (Jorio, A. 1827) (Ruggiero, M. 1885, X).
[74] (Kuniholm, P.I. 2002) (Adam, J.P. 2004, 18-20) (Buccaro, A.; De Seta, C. 2014, 199)

charred woods and the difficulty of extracting them from the solidified volcanic ash,[75] together with the low interest in these components in the early archaeological campaign, explain the absence of references to them in the excavation reports and also the heavy on-site destruction in the 1780s. Based on excavation diaries (*Giornali di scavo di Ercolano*, GSE) and restoration campaigns (1994-1998), De Carolis argues that when the timber findings of Herculaneum were discovered, the majority of these were still *in situ*, and substantially intact due to the specific conservation conditions. The fragmentation and partial harm of their parts started only after the separation of these findings from the compacted mass of pyroclastic materials. Original wooden elements are restored by paraffin from 1920s to 1980s and, in general, disguised as ancient components. Thus, the wooden findings that are still preserved come from the more recent open-air excavations of 1927. Maiuri describes the conservation process of the charred wooden components with a hopeful and enthusiastic tone.[76] Later, De Carolis refers to problems related to the conservation of the wooden evidence and the different restoration methodologies over the centuries, as testified by a number of documents in the archives of the *Soprintendenza di Pompei*.[77]

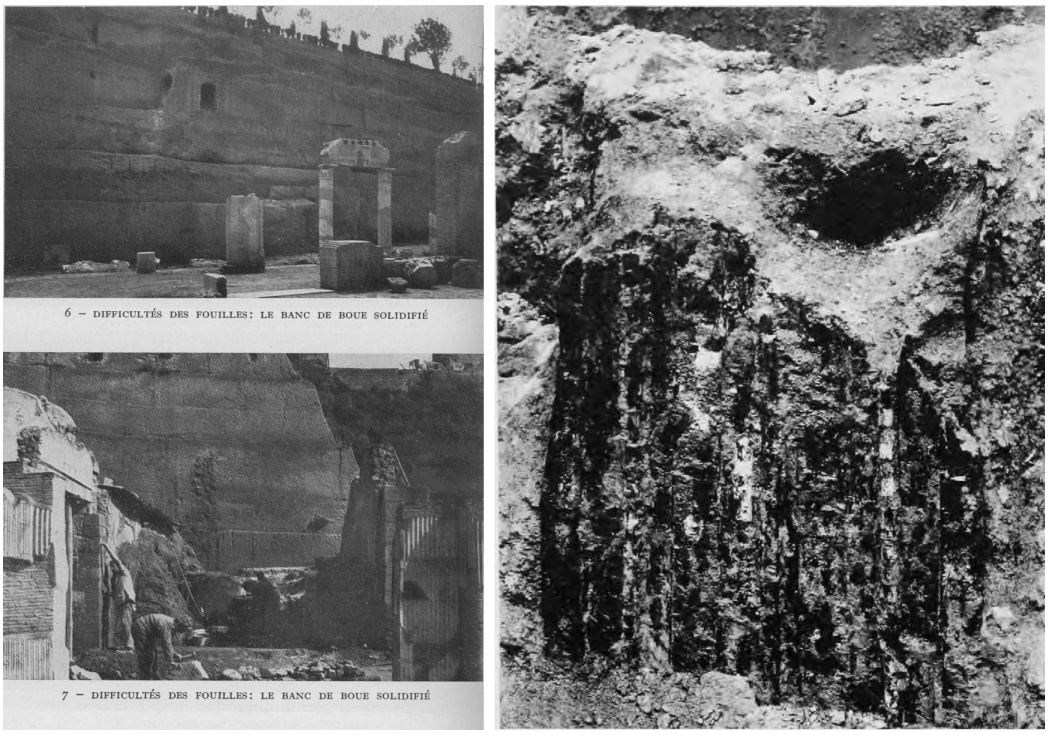

Figure 1.04 – Difficulties and valuable discoveries: the solidified mud bank (Maiuri, A. 1976, 92) and wood immersed in the alluvial rock (Maiuri, A. 1958, 22)

[75] Due to the chromatic difference between the wood and the volcanic ash, the timber components were easy recognizable. As regards their weakness, Venuti notes: "All of the wood is black like coal, most of it preserved shiny and intact, but as soon as it is touched it crumbles and its lines and filaments are visible"."Tutto il legname è nero come carbone, mantenuto in gran parte lucido e intero ma appena toccato si stritola e vi si vedono le sue linee e filamenti". (Venuti, N. M. 1748, 136).

[76] (Maiuri, A. 1958, 23)

[77] Early methods of wood restoration included the immersion of the findings in containers and the application of liquid wax using brushes; later tmixed with carbon black in order to avoid staining whitish arising to the previous application of the wax. The wax was employed to connect different fragmented finds, while iron, wood, or reinforced concrete components were employed as supports. Any new components were introduced with a sort of chromatic simulation by employing a mixture of wax, carbon black and crushed charred wood. In fact, the wood grain was drawn on the restored component by means of a comb, then a liquid wax was applied to homogenise the surface (De Carolis, E. 1998, 52-55, passim).

1.3.2 A brief look at the excavation campaigns of the 1780s and 1930s

The main archaeological campaigns at Herculaneum were executed in two phases, through the underground tunnels under the *Borbone* government, so-called *cunicoli borbonici*[78] (1738-1780), and the open-air excavations (*sub divo*) by the architect Carlo Bonucci (1828-1855), by the archaeologists Giuseppe Fiorelli (1869-1874) and Amedeo Maiuri (1927-1961) (*Figure 1.05*).



Figure 1.05 – Archaeological site of Herculaneum: *Borbone* excavations (1828-1855) in dark grey; excavations from Fiorelli to Maiuri (1869-1924) in light grey; Mauri excavations (1927-1961) in white, map adapted from (Catalano, V. 2002, plate no. 2)

These mentioned excavation phases, separated by two centuries, are discussed below with a historicizing perspective on the works coordinated by La Vega and Maiuri respectively. While these campaigns were undertaken with antithetical research methodologies – underground excavation *versus* open-air excavation – they are united by an abundance of relevant findings and a certain exploitative attitude. Other theoretical and practical shortcomings may be noted: during the 18th century, the intrusiveness of the excavation works and the interest in only archaeological vestiges of precious materials; in contrast, during the 20th century excavations, Maiuri's method, while refining the way data was catalogued, used anastylosis to pursue a preconceived ideal.[79]

[78] "cunicoli: an Italian term based on the Latin for 'rabbit holes' (cunicula) to describe the 'rabbit warren' of tunnels made by the early explorers of Herculaneum" (Wallace-Hadrill, A. 2011, 345). The tunnels were approximately 0.80-1.00 m wide, 1.70-1.80 m high, with a depth of 20 m.

[79] Adam also refers to several structures in Pompeii that had undergone heavy restoration during the 19th century whose legibility arises from the wood ageing (Adam, J.P. 2004, 135), and Wallace-Hadrill warns: "We have to

Papaccio and Salvatori explain how these excavation methodologies differed by passing from a "sclerotic treatment of the ruins to heavy reconstructions justified by the massive user requirements", [80] in spite of Maiuri's declared desire to harmonise the past and current campaigns.[81]

As regards the first phase, the interest in frescos and in furnishings made from precious materials (e.g. marble and bronze) prevailed, and this approach was reflected in the collection and conservation activities. The ancient findings were appreciated only for their decorative elements or in terms of evidence of daily lives, rather than for their technological value. In addition, the excavation techniques employed during the *Borbone* governments were highly invasive and caused irreversible loss, also due to the physical fragility of the vestiges and the changes in environmental conditions following their extraction. Thus, despite the considerable frequency of the discoveries of wooden components, very few cases were described in the early reports dated from 1738 to 1765.[82] Despite the low interest of the diggers in analysing the Roman construction techniques, the archaeological discoveries strongly influenced contemporary artwork (e.g. painting), and from there the Neoclassical movement established itself throughout Europe.

The archaeological discoveries during the 18th century may be interpreted as *Rechtfertigung*, a project intended to legitimise the royal power of that time.[83] Agnes Allroggen-Bedel emphasizes the exploitation of the archaeological works under the Neapolitan court. The author contests the idealised view of Carlo of *Borbone* Court as a disinterested *instaurator artis* by describing the initial reluctance of the court to proceed with the archaeological excavations for nine months at his own expense, following the accidental discovery of precious vestiges by the Prince Elboeuf in 1709. In 1709, the engineer Stendardo was seeking crushed marble near Portici for the plaster for the new villa of Prince Elbeuf of the house of Lorraine. He learned from the peasants that some pits existed from which they not only quarried excellent marble, but had also extracted many statues and antiquities over the years.

Thirty years after the early discovery, the Neapolitan Court committed to the construction of the contiguous *Reggia reale* in Portici (1738-1742). The palace was enriched by an exuberant decorative structure with frescoes and a monumental marble staircase, with the nearby excavation area intended as an attraction for privileged guests. Cultural monopoly was expressed in the *Borbone* government's restrictive regulations. These prohibited foreign printers from publishing documents regarding the Vesuvian findings and prohibited visitors sketching or writing during the visits. From a letter from Tanucci to a Florentine friend: "the king is the jealous

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remind ourselves continuously that what we see is not the raw evidence, but a re-presentation, one done with consummate skill by an outstanding archaeologist, but incorporating his own interpretations" (Wallace-Hadrill, A. 2011, 74).

[80] "sclerotizzazione ruderistica e la ricostruzione massiccia giustificata dalle esigenze di massa" (Papaccio, V.; Salvatori, A. 1988, 201).

[81] (Maiuri, A. 1958, 22)

[82] As mentioned by De Carolis, greater attention has been given to the carbonized findings and other organic-based objects of Herculaneum from academics since the 18th century, as well as the Neapolitan naturalist P. Giovan Maria della Torre in 1745, and some French scientists (e.g. Lalande, the abbot Richard and Roland de la Platière) that visited the tunnel in the second half of eighteenth century (De Carolis, E. 1998, 44). They agreed that the burial of the findings had caused its carbonization, which otherwise would have been directly exposed to fire and destroyed. Roland de la Platière observed that the presence of wooden vestiges demonstrated the difference between the burials of Herculaneum and nearby Pompeii, even if caused by the same eruption activity (Grell, C. 1982).

[83] (Dell'Orto, L.F. 1993, 35-39)

guardian of any antique piece, and he is disgusted by the news that something has been sold by fraudulent diggers to a certain Roman".[84]

The next stage is no less controversial, in which the political system figured out that Maiuri would be the best personality to tenaciously boost the image of Herculaneum and distinguish it from the more popular Pompeii.[85] The intent to reconstruct an *open-air museum* prevailed, with a didactic and evocative purpose of exhibiting the findings in display cases and explaining the construction layer of floor and wall structures through a sort of exploded axonometric view, defined by Wallace-Hadrill "a *cut-away effect* of restoration"[86](*Figure 1.06*, left). His aim was to literally reconstruct for the community the material image of the past, rescuing it from the ashes.

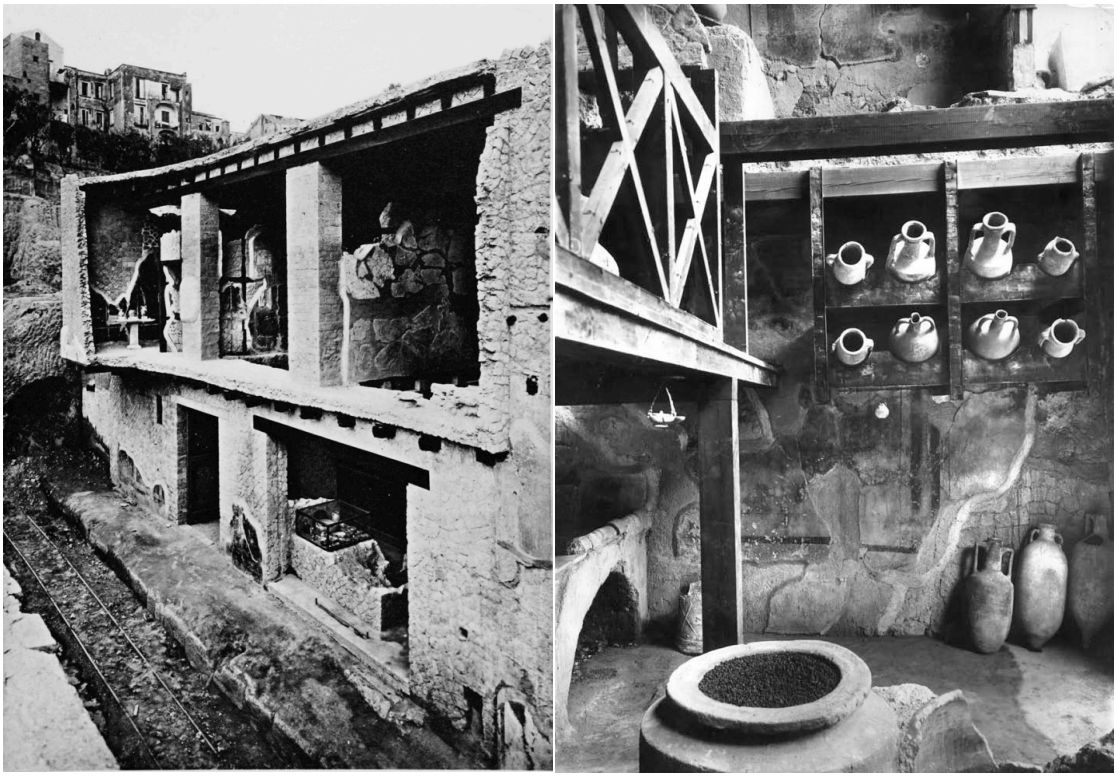

Figure 1.06 – Main elevation of *Casa di Nettuno e Anfitrite* (Maiuri, A. 1958, 395) (left); internal view of the workshop of *Casa di Nettuno e Anfitrite* (Catalano, V. 2002, plate no. XLIX) (right)

[84] "Il re è si geloso custode di qualunque pezzo di anticaglia, che si è disgustatissimo per la notizia che qualche cosa sia stata venduta dalli fraudolenti scavatori a alcun Romano". King Carlo III claims as exclusive, sovereign privilege, not only the possession of the even the smallest fragments, but also the right to reproduce or draw the figure. As an example, Observations dans lacause des abbayes de Chésal-Benoît, sur les nominations royales was written by Cochin Legouvé and Baptiste in 1753: the low quality of the drawings could result from this prohibition of on-site reproduction.

[85] In addition to the excavations at Herculaneum, the works of this period include the areas of the Imperial Forums, of Palatine, of Capitoline Hill: "The great aim of the fascist regime was to show its greatness to the world through the reconstruction of entire cities and buildings as symbols of Italian supremacy."*Ita*: "Il grande intento del regime fascista era quello di mostrare al mondo intero la sua grandezza attraverso la ricostruzione di intere città e edifici simbolo della supremazia dell'italianità." (D'Angelo, D.; Daniele, G. 2004, 27-30).

[86] (Wallace-Hadrill, A. 2011, 80-81)

1.3.3 Historical perspective of La Vega's mandate at Herculaneum

Going back to the 18th century, the underground excavations carried out by Alcubierre were preferred for almost thirty years to other methods[87] because these methods obviated expensive expropriation from Resina's landowners. As the arduous works were proceeding into the volcanic mass by the *cavamonti* (diggers), the works and the material extractions were supervised by guards against intruders, thieves, and any onlookers. The tunnels were grounded on masonry pillars placed to prevent collapse of the upper levels. Territorial control had been assigned to the military for the execution and maintenance of a defensive system, as well as for topographical surveying, and they were indispensable during the archaeological campaigns as the earliest excavation methods involved the use of explosives.[88] These digs were carried out in absence of even a vague idea of the urban layout of the ancient town, a trial and error process. Exhausted tunnels were refilled, with the result that the workers often later found themselves digging in places they had already carved into the volcanic rocks. These excavations caused cracks and irreversible damage to the ancient buildings that led to partial or total reconstructions during the following phases.[89]The precise extent of the excavated area during this phase is thus uncertain; some evidence comes from the painted walls, which were discovered, detached, and listed in the excavation report, and later collected in a museum in Portici.

After Weber's[90] death in February 1764 due to extensive exposure to the insalubrious underground conditions at Herculaneum, La Vega – under the protective wing of Tanucci – was assigned as new director of the excavation campaign to find the missing documents of his predecessor. La Vega took a personal and proactive role in this controversial early campaign.[91]The literature points out how the scientific survey method goes back to the mid-1700s with an international backdrop of cultural interest and development of the applied sciences[92]; on the other hand, persistent effort can be attributed specifically to Weber and La Vega. Several scholars hold La Vega apart from other, negatively-viewed leaders of the campaign.[93]

Having been trained at the *Accademia di San Luca* in Rome, where the ancient Renaissance and Berninique structures were analysed in detail and replicated according to a set of formal variations (following Bellori's theories), La Vega had strong technical knowledge and classical training. As stated by Pezone, little information is known about his studies, except that they were financed by the treasury through the intercession of King Carlo III and that La Vega distinguished himself by winning the first-place award in a 1762 competion for a

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[87] From 1738, the exploratory campaign of the ancient city was carried out by Carlo di Borbone's government under the supervision of the military engineer Roque Joachim de Alcubierre. Alcubierre was assisted by the architect Karl Weber and, from 1764 until 1780, by the engineer Francesco La Vega. La Vega was the director until his death in 1804, followed by his brother Pietro La Vega (1804-1814). Some reports were likely written by Pietro before this date, when Francesco had to participate to other works (Pagano, M. 1997, 11).

[88] (Pezone, M.G. 2003) (Murga, F. 1964)

[89] (Monteix, N. 2008, 184)

[90] Parslow underlines the contribution of the Swiss-born military engineer Karl Weber to the Pompeian archaeological discoveries. In particular, the scholar refers to the isometric view of *Praedia* of Julia Felix (Pompeii), made by Weber between 1755 and 1757, unpublished until being discovered by Ruggiero and sold 1879. This illustration was complementary to the conventional site plan, and it included descriptive commentaries from classical references (Theophrastus, Tacitus) (Dell'Orto, L.F. 1993, 51-56).

[91]While not wading into the full controversy about this method of the excavations and the general attitude of the protagonists of this phase, we may refer to some early objections by the illustrious traveller Charles de Brosses, who, together with the German abbot Winckelman, compares the Herculaneum excavations to a lamentable sacking and quarrying, carried out haphazardly in search of wealth rather than to rediscover the memories of a lost civilization. (De Brosses, C. 1836)

[92] (Zevi, F. 1988)

[93] (Ruggiero, M. 1885, XIV)

project for a prince's palace and a praiseworthy project for a fountain as a scholarly exercise.[94] The attentive study of ancient architecture is the golden thread that connects all the most significant episodes of his career: "Francesco La Vega had made patient study of the ancient works the strong point of his activity in the direction of the excavation project".[95] La Vega embodies the three sides of Neoclassical art *ante-litteram*: the archaeology, the engineering, and the architecture.[96]

Probably due to his Roman studies of mathematics, archaeology, and architecture, or because of his personal attitude, La Vega organised the underground excavations in Herculaneum by dividing them into zones and also by trying to leave the ancient structures visible. Marquis Berardo Galiani, in charge of reviewing the drawings of the Herculaneum theatre from 1753, states that La Vega was a "youth of high and well-tested value" ("giovane di sommo e sperimentato valore") (Doc.E.p.456). The importance of La Vega's publications is also emphasized by Winckelmann.[97] Similarly, Maiuri, Zevi, and De Simone underline his contribution to the reconstruction of the topography of Herculaneum through a geological approach.[98] In fact, the illustrations compiled by La Vega and included in Rosini's *Isagonic Dissertation* (1797)[99] testify an early awareness of the specific features of Herculaneum's archaeological environment. Zevi comments that La Vega's map "has value especially as an early essay of topographic interpretation of the urban organism"[100] since it surpasses Cochin and Bellicard's representation (1754) that lacks the topographic context. The significance of his work may be understood by considering that, despite the inaccuracies in La Vega's map – following the information gathered during the *Borbone* excavations – the 1986 excavations were based on his drawings[101] (*Figures 1.07*, *1.08*).

La Vega's thought is crucial regarding the archaeological findings, the structural function, and the importance of some of the discovered construction techniques – among which were fragments of the *parietes craticiae*. It is less easy to elucidate the extent of his influence on the use of the timber frame wall during the rebuilding of numerous towns in provinces of the Neapolitan kingdom Calabria in 1783. He was named as inventor of this system by Maiuri-Mori since La Vega was involved in the Calabrian reconstructions;[102] however, this theory is questionable, as shown in *Chapters 3* and *4.*

Leaving aside the hypothesis of an influence from the Herculaneum findings, another possible cultural conditioning factor is the similarity of the building tradition in the area of La Vega's home in Campania region but with a clear Spanish influence, to the building system that later was adopted during the Calabrian reconstruction.[103]

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[94] (Pezone, M.G. 2003, 74-78, 87)
[95] Ibid., 84
[96] Ibid., 170
[97] (Dell'Orto, L.F. 1993, 51)
[98] (Maiuri, A. 1958, 27) (Zevi, F. 1980, 61) (De Simone, A. 1990, 68)
[99] The *Dissertatio Isagogica ad Hercolaneum volumina explicationem* (Nespoli 1797) was republished in (Ruggiero, M. 1885). The initial print is embellished with watercolor exemplars of volcanic lavas (Pagano, M. 1997, 106, 117).
[100] "ha valore soprattutto come precoce saggio di interpretazione topografica dell'organismo urbano" (Zevi, F. 1988, 61)
[101] The documents that La Vega collected meticulously and updated to allow understanding of the findings were kept personally by himself, and then after by his brother. His brother died in 1814 and many papers came to Andrea De Jorio of the *Borbone* museum, who catalogued them, but these were partially lost after Jorio's death in 1851 (Pagano, M. 1997, 11).
[102] (Mauri-Mori, G. 1909, 89-90)
[103] *Chapter 3, section 3.3.2*



Figure 1.07 – Map of Herculaneum drawn by La Vega (Maiuri, A. 1958, 9)

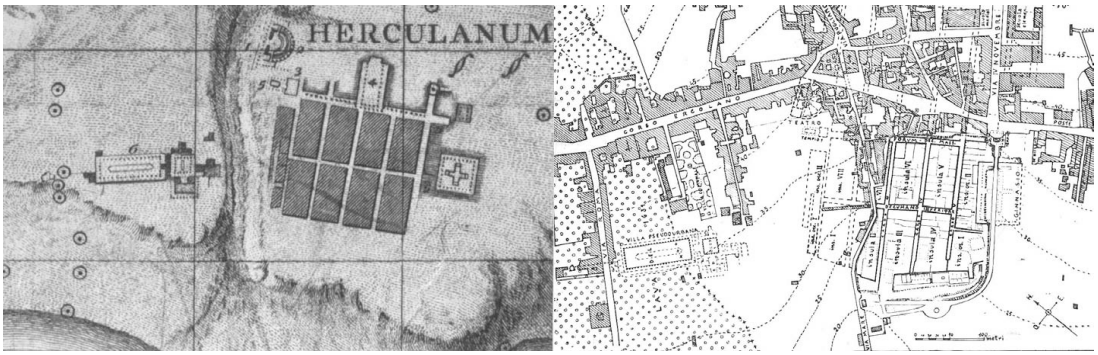

Figure 1.08 – Plan view of old and new excavations (1738-1963) (Catalano, V. 2002, plate no. 1)

The cultural and political climate in the 18th century obviously cannot be neglected, foremost by considering the state of the scientific debates on the causes of earthquakes and on effective anthropic responses to them.[104]

[104] (Bologna, F. 1992, 81)

1.4 Physical evidence of timber frame walls in the Vesuvian towns: provenance and tools employed in construction

There were difficulties in digging up, interpreting,[105] and preserving the ancient wooden artefacts, especially in a rich context such as ancient Herculaneum. Regarding this, Maiuri describes:

> "(…) we should not forget the enormous difficulties that modern diggers have to deal with, with all the scientific requirements that the current study of antiquities imposes, to uncover damaged walls, detached plaster and stucco, destroyed beams, thin partitions made with this particular technique of lightweight materials that Vitruvius called opus craticium, and finally recover the fine furnishings of a house in bronze, iron, terracotta, glass, and wood, and separate them from a hard compact mass, sometimes almost petrified."[106]

The stratigraphic survey is a fundamental tool for the evaluation of the archaeological evidence,[107] both for walls or soils, as well as for layers of structures that have already been excavated and that require a dating process.[108] Nevertheless, stratigraphic excavations would only be employed in Italy starting in the 1980s.

Carandini remarks: "Certain archaeological maps look like telephone books", [109] simple lists of evidence accompanied by almost no analysis. This assertion, referring to the excavations within Italian rural areas, whose rich heritage makes it impossible to do a typological analysis of the *villae*, is also perfectly applicable to the Vesuvian environment. The same difficulties, such as recording and collecting data, and defining measures for the protection of the findings, are stressed in other archaeological contexts, e.g. Minoan findings from the Bronze

[105] Bacchetta describes the archaeological evidence from the 2nd century BC to the 4th century AD in another context, Padania (Bedriacum/Calvatone, Italy). These vestiges are divided into three types: *opus craticium*, *pisé,* and *adobe*. The researcher underlines the difficulty in interpreting the archaeological remains in cases of collapsed buildings, namely in distinguishing the *opus craticium* from *pisé* (rammed earth), despite their substantial differences in construction. The same interpretive problem is mentioned by De Vos in relation to the archaeological wood in *Satricum* (modern Le Ferriere, Latium) in *villa* in Isera (De Vos, M.; Ciotola, A.; Allavena, L. 1992, 52). References to the key topics of the selective perception, the conservation of the *material evidence*, and the cross-cutting observations in the stratigraphic analysis are made by Quendolo, by including relevant bibliographic references (Quendolo, A. 2008, 11-18).

[106] "(…) non si devono dimenticare le enormi difficoltà alle quali si trova innanzi lo scavatore moderno, con tutte le esigenze scientifiche che lo studio delle antichità oggi impone, per liberare ed enucleare dalla massa dura e compatta, a volte quasi petrosa, pareti lesionate, intonaci e stucchi distaccati, travature abbattute, sottili tramezzi di ambienti fatti con quella particolare tecnica di materiali leggeri che Vitruvio denominava opus craticium, e per ricuperare infine la minuta suppellettile di una casa, in bronzo, in ferro, in terracotta, in vetro e in legno." (Maiuri, A. 1958, 20).

[107] The archaeological evidence can be divided into *primary* and *secondary*. The first type comprises the on-site findings with most of the cases classified as *negative* (e.g. holes or trenches dug in the ground for wooden foundation stakes) or *positive* (e.g. stones or wood in specific environmental conditions); the second type corresponds to collapsed parts (e.g. fragments of plaster or floor with imprints of straw from the framework) (Bianchini, M. 2010, 11-15).

[108] "L'archeologia applica ormai da tempo (…) una lettura stratigrafica non solo al coacervo di mura, suoli e materiali mobili, che è il tradizionale deposito archeologico, ma anche a quelle strutture murarie che sono già state scavate o non sono mai state interrate e ciò che si ottiene non è soltanto la soluzione di alcuni problemi di datazione relativa, ma la comprensione delle modifiche e aggiunte subite dagli edifici nel tempo mettendole in relazione tra loro. (…) Rimane talvolta problematica l'individuazione della conoscenza delle preesistenze e delle fasi di fondazione delle strutture edilizie ancora in piedi" (Francovich, R. 1988, 20).

[109] "Certe carte archeologiche somigliano ad elenchi del telefono" (Carandini, A. 1988, 48).

Age.[110]

Concerning the provenance of the building materials used in the Vesuvian environments, local materials were preferred, but several components were also obtained through trade with other regions.[111] Campanian merchants selected building materials such as wood to import and use.[112]

A reserve forest was located in Vesuvius itself and in the surrounding areas, the so-called Lattari Mountains that were less populated than at present. This reserve in close proximity to Herculaneum and Naples was significantly more extensive at that time. It was characterized by a diversity of wood species, especially on the East and Southeast sides and near the coastal strip. According to Adam, this forest could satisfy the demand of wood for buildings and shipyards.[113]The wood was carried over the shoulder or dragged by beasts of burden,[114] later being left in storage places, as mentioned in the ancient sources (e.g. Seneca).[115]

The helical frieze of Trajan's Column (113 CE) in Rome offers depictions of woodworking during the Roman Age from which the marks left by working tools can be deduced[116](*Figure 1.09*).



Figure 1.09 –Trajan's Column in Rome: scene of abatement, transport, and storage of wood (Camardo, et al. 2015, 275)

The most commonly employed wooden species in ancient Herculaneum was the same recommended by Vitruvius, the *Abies alba*, used both for building construction and for interior furniture,[117] as confirmed by ancient sources and by recent laboratory testing.[118]

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[110] (Tsakanika-Theohari, E. 2008)
[111] (Camardo, et al. 2015)
[112] (Kuniholm, P.I. 2002, 237)
[113] (Adam, J.P. 2004, 214)
[114] These workers, known as *dendrophori*, were a privileged guild dedicated to tree felling and the transport of the wood.
[115] (Camardo, et al. 2015, 275)
[116] (Adam, J.P. 2004, 94-6) (Ulrich, R.B. 2007, 101) (Camardo, et al. 2015, 294)

Kuniholm alleges that the Romans preferred spruce during the late stage of the Republic period, substituting it with fir when spruce was not available. The author opens a new perspective on the traditional delivery routes and supply sources, by analysing a large number of samples (e.g. sixteen timbers from Herculaneum and seven from Pompeii) through dendrochronological cross-dating.[119] On this basis, Kuniholm asserts that the wood floated down the Adige river to the Po estuary from which it was transported by ship to Herculaneum and Pompeii.

As regards the filling of the timber framework, very stiff materials (i.e. *opus incertum*[120] or *opus mixtum* or brick masonries) were very common, whereas adobe filling prevailed in rural or humbler contexts.[121] River pebbles, fragments of roof tiles and dolia (ceramic fragments) were also employed for *opus incertum*.[122]

Lugli refers to infill of clay and stone, or earthy cement mixed together,[123] whereas Pliny refers to *luto* (*N.h.* 35, 48), which corresponds to clay, as witnessed by the findings in Acquarossa and in Lavinium (second half of 7th century BC), 58 km South of Rome.[124]

The type and the arrangement of these raw materials greatly influence the resistance of the construction system. In particular, the degree of strength and elasticity is relevant in the wooden and vegetable components, whereas the degree of cohesion and compactness is more important as regards the infill components.

[117] (Mols, S.T.A.M. 2002)

[118] (Kuniholm, P.I. 2002) (Camardo, et al. 2015, 294). The archaeological campaign in *Casa del Rilievo di Telefo* in Herculaneum (*Insula Orientalis I*) took place from August 2009 to June 2010, with the aim of identifying the wood species of the roof and the ceiling, and also of making a virtual reconstruction of the roof system through a systematic data collection on 250 collapsed components and 3d laser scanning. The analysis of this house's timber components deepened the knowledge of the carpentry works from the Roman Age (Camardo, et al. 2015) (Choay, F. 1986).

[119] (Kuniholm, P.I. 2002)

[120] As opposed to the regularity of *opus reticulatum*, the *opus incertum* consists of masonry of rough stones set in mortar, whose strength depends on the wall joints structure. In fact, the laying of horizontal rows offers paths for cracks to more easily develop in the *opus reticulatum,* and this drawback is overcome in the walls made in *opus incertum* (*D.a*. II.8.1).

[121] (Laumain, X.; Sabater, A.L. 2012, 1216)

[122] (Papaccio, V. 1993, 612)

[123] It refers to the *opus caementicium*, executed with mortar (i.e. 1 part – by weight – of hydrated lime and 3 parts of sand) and *caementa* (i.e. rough stones, shards, and chips of tufa, travertine, pieces of flint, bricks, and broken tiles) (Lugli, G. 1957, 44, 48).

[124] (De Vos, M.; Ciotola, A.; Allavena, L. 1992) (Ulrich, R.B. 2007, 98)

1.4.1 Critical overview of the present vestiges

Among many different types of vertical structures, timber frame walls have been unearthed over the centuries leading up to the recent archaeological campaign within the *Herculaneum Conservation Project*.[125]

The earliest examples of this type of walls date from the late Augustan period, although this tecnique was employed prior to this epoch. *Craticii parietes* in Herculaneum are composed of a wooden skeleton filled with yellow green-tuff blocks, *cruma* (red lava foam), and other materials.[126] These walls can be divided into two groups depending on their location: (i) the external walls (including the balcony) – on the upper level, whereas the ground floor is in masonry or brick works; and (ii) the internal partitions on the ground floor[127] and upper floors.

The walls are arranged by a continuous and modular frame of 50-80 cm wide, generally without bracing components. The wall structures are subdivided by vertical squared posts of 8-12 cm per side, so-called *arrectaria*, whose height corresponded generally to the elevation of the entire wall of the building, and by small horizontal components, so-called *transversaria* of 6-8 cm in width. These wooden components are connected by mortise-tenon joints and rivets; each square frame is filled with *opus incertum* or *opus mixtum*, or brick masonries.

In cases of timber framework in the external facade (i), the lightness of this construction system allows an increase in the height of the upper-floor housing by ensuring a proper distribution of additional loads.[128] These walls, directly supported by the floor structure, are parapets composed of a single frame or divided into three or four frames for the height of the room.[129] Joists orthogonal to the facade support a continuous timber beam that bears the timber framework infilled with *opus incertum*. This is the case of the so-called Roman *maeniana*,[130] where the facade overlooked the main streets, e.g. in *Via dell' Abbondanza* at Pompeii.[131] *Maenianum* is a Latin term that indicates the balcony, derived from Maenius, a Roman consul in 338 BC who allowed the construction of timber overhangs for the Roman spectacles in 318 BC, as suggested by Sextus Pompeius Festus in the later 2nd century AD.The use of the *craticii parietes* in the external facade demands an alteration of the formal composition of the building, by squeezing the proportion of the facade through an inversion of the ratio between the height of the ground floor and that of the upper floor (e.g. *Casa di Nettuno e di Anfitrite* – whose denomination arose from the magnificent polychrome mosaics of glass paste in the external nymphaeum,[132] *Figure 1.06* – or by lowering the overall elevation (e.g. *Casa a Graticcio*, *Figure 1.10*).

In cases of internal timber frame walls (ii), the thinness of the partitions allows the limited floor space to be more easily organized while still providing some insulation. These partitions divide either secondary or principal spaces: the wall structure was completely hidden by figurative and frescos or, more common, by plain white

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[125] Founded by David W. Packard in 2001 with the Agreement Protocol between the non-profit *Packard Humanities Institute* (PHI) and *Soprintendenza Archeologica di Pompei* (in 2008 renamed the *Soprintendenza Archeologica di Napoli e Pompei*), the *Herculaneum Conservation Project* aims to safeguard both the archeological and decorative structures at this site.

[126] (Andrews, J.N. 2006, vol.1, 164-165)

[127] With regard to the timber frame walls in Roman provinces, the majority of the archaeological findings are masonry plinths that were the levelling planes on which the *craticii* were executed.

[128] In some cases the overhanging structures were not executed with timber frames, i.e. in Pompeii, the *Casa del Balcone pensile* (VII,12,28), discovered by Giuseppe Fiorelli and restored by Amedeo Maiuri, and the brothel *Lupanare* (VII,12,18) dating from the late period of the construction of the city.

[129] (Spinazzola 1953, 102)

[130] "Maeniana appellata sunt a Maenio censore, qui primus in Foro ultra columnas tigna frofecit, quo ampliarentur superiora spectacula". (Festus, S.P.; Müller K. O. 1880, 134)

[131] (Adam, J.P. 2004, 133)

[132] The bibliography on *Casa di Anfitrite e Nettuno* is listed by (Andrews, J.N. 2006, vol.2, 185), which includes the description of Maiuri's works, whose excavation was carried out from 1932 and 1934 (Maiuri, A. 1958, 393-403).

plaster, in such a way that this construction solution was not distinguishable from brick or stone masonry surfaces. Many constructions built pre-62 AD (e.g. *Casa del Larario di Achille*, *Casa di Nettuno e di Anfitrite*) show earlier plaster on the *craticium.*

Regardless of their internal or external location, the original load-bearing capacity of the frame walls at Herculaneum is completely lost[133] due to the on-site burial, the damage caused by the excavations since the 1780s, and the works of the 1930s. In the latter phase, metallic structures, new infill, modern timber frame with some original casting pieces, and consolidation with paraffin were widely employed in the findings discovered from 1927 to 1970 and restored until the early Eighties (*Figure 1.11*).[134]



Figure 1.10 – Top-floor loggia in *opus craticium* in *Casa a Graticcio* (Catalano, V. 2002, plate no. XXIV)



Figure 1.11 – Effects of old consolidations of wooden components at Herculaneum (© S. Stellacci)

[133] In spite of the progress of the fieldworks methodology, especially after the works carried out by Carlo Bonucci from 1828, the state of deterioration of the timber structures has worsened considerably: "(…) most of the walls fell down, no analysis was made of the ancient timber structures, and what remains of the construction is pitiful". *Ita*: " (…) gran parte delle mura caddero, nessuna investigazione fu fatta delle antiche strutture in legno e quel che si supplì di fabbrica è una compassione vederlo". (Ruggiero, M. 1885, XVII)

[134] (De Carolis, E. 1998)

In addition to the *Casa a Graticcio* (discussed separately in section *1.4.2*), Papaccio lists construction at Herculaneum with timber frame walls in six houses, two small shops, and a religious building.[135] In Pompeii, the scholar cites *Casa del Moralista* or *Casa di C. Arrius Crescens e di M. Epidius* (III 4, 2–3), *Villa di Diomede*, *domus della Regio I* (10, 1-3), and *Casa di Caius Iulius Polibius* (IX 13,1.3). Another notable case with *craticii parietes* is a small *domus* of 290 sqm in Pompeii, *Casa dei Ceii* (6,15) discovered by Spinazzola in 1913 and described by Anguissola.[136] A staircase including *craticii parietes* leads to an upper floor, which was never completed due to the eruption. A similar mixed technique was also found on the upper floor of *Casa d'Argo* (II, 2). The walls in *opus reticulatum* and the partitions in *opus craticium*, discovered during the open-air excavations undertaken by Bonucci until 1837, were demolished in 1875 because of the instability of the whole structure. The discovered configuration of *Casa d'Argo* has been transmitted through the detailed reports of Bonucci, Ruggiero, and Maiuri.[137] "It was the first clear and sharp example of those *maeniana* and of those foreparts that today constitute one of the most characteristic aspects of the houses in Pompeii and Herculaneum".[138]

What follows are brief remarks on the existing archaeological findings regarding: (i) the connections of the internal framed partition to the external wall and to the floor system; (ii) the absence of diagonal members; (iii) the regularity of the subdivisions of the surface wall into frames; (iv) the joints; and (v) the covering surface.

(i) It is noteworthy that the wall should not be analysed as a single element, because it is included in a whole system made of interacting components. The connections of the *craticii parietes* to the floor timber structure (*contabulatio* or *contignatio*)[139] and to other types of walls (namely the external wall) represent a critical point in the overall behaviour of the building.

Physical evidence shows how this type of wall was executed after the construction of the floor and roof, as simple partition in order to subdivide the interior space. As an example, in the timber frame in the *College of the Augustales* (VI, 21), the absence of technical devices (e.g. metallic fasteners and interlocking) to connect the timber frame wall to the orthogonal structure (i.e. the external masonry wall) demonstrates that this was a later alteration of the original layout (*Figure 1.12*).



Figure 1.12 – Internal view of *College of the Augustales* (VI, 21): detail of timber beam and of timber frame wall (© S. Stellacci)

[135] The houses: *Casa del Bicentenario* (V, 13-17), *Casa del Tramezzo carbonizzato* (III,11-12), *Casa di Argo* (II, 2), *Casa di Nettuno* e *Anfitrite* (V, 7), *Casa dell'Atrio a Mosaico* (IV, 1), *Casa del Bel Cortile* (V, 8); the stores: *bottega sul III cardo* (V, 6), *bottega sul decumano Massimo* (V, 21) (Maiuri, A. 1958, 441), and the religious building (e.g. *Collegio degli Augustali* (VI, 21) (Papaccio, V. 1993, 611).

[136] (Anguissola, A. 2012, 152)

[137] (Maiuri, A. 1958, 6, 360-372, 476)

[138] "Era il primo chiaro ed evidente esempio di quei menianie di quegli avancorpi pensili che costituiscono oggi uno degli aspetti più caratteristici della casa pompeiana ed ercolanese" (Maiuri, A. 1958, 363).

[139] From *tignum* meaning beam. In relation to the most common technical terms of Roman woodworking, Ulrich provides a very useful cross-indexed glossary with quotations from Latin researchers (Ulrich, R.B. 2007, 269-335).

In the *College of the Augustales*, the timber frame wall was executed in a second phase for a subsidiary function (to delimitate the keeper's room), detracting from the decorative scheme and compromising the inner spatial layout based on four central columns and perimetral blind arches. In other cases, the vertical posts at the end of the timber frame wall were placed next to the orthogonal main wall without any transversal connections, whose anchor devices remain unclear due to the surface finish applied in the 1930s.

(ii) While stating the incompleteness of the archaeological excavations in Vesuvian towns,[140] Adam argues that the use of bracing components (so-called *traversa sbieca* or *saetta*) is rare in the Roman vestiges.

Romans did not employ diagonal components. The consequence of this is not marginal: the execution of bracing diagonals increases the time of construction of the wall and the degree of its difficulty. However, in terms of structural performance, the frames assume the behaviour of non-deformable triangles: the timber frame walls with these diagonal elements are then able to withstand the seismic effects related to 45° cracking. [141] Following Adam's assumption, [142] it is a common belief that in the only exception so far discovered, timber diagonal elements can be found in the internal east wall on the upper floor of *Villa of M. Arrius Diomedes* at Pompeii (room 18) (*Figure 1.13*), although the wooden components were later replaced by plaster. This case with traces of bracing components does not belong to a common Roman housing lot, but is included in an ambitious building plan for rich dwellers that would have implied more accuracy in the execution of the construction system. However, the authenticity of this timber frame wall is unsound, as recently stated by Doctor Hélène Dessales, during the archeological campaign in the *Villa* of *Diomedes* in 2013.[143] This wall was heavily reconstructed during the *Borbone* excavations by introducing timber diagonals, whereas the upper section made of masonry stones and yellow tufa (without any timber components) could be made of Roman materials.

(iii) The *craticii parietes* are subdivided into squared frames. The regular geometry, implying an increase of the structural reliability under dynamic loads, will be lost during the Middle Ages in the Portuguese timber frame walls, where unequally-sized squares prevailed.[144] There is a dimensional correspondence between the width of the timber frame and the width of the doors (e.g. *Casa del Bel Cortile*). The empty parts of the frame represent a weak structural point. Small windows were therefore executed into the frame and did not correspond to the

[140] "The only preserved Roman examples are found in Herculaneum and Pompeii and it should be remembered that these case studies constitute Roman [urban] architecture, while the rural examples, perhaps still buried under the ashes of Vesuvius, escape us altogether. For this second category the archaeological findings consist of masonry plinths surrounded by aggregating stones on which the structures are arranged in perishable materials such as timber frames or pure clay". *Ita*: "Gli unici esempi Romani che si siano conservati si trovano a Ercolano e a Pompei, e va ricordato che si tratta di esempi di architettura Romana, mentre gli esempi rurali, forse ancora sepolti sotto le ceneri del Vesuvio, ci sfuggono del tutto. Per questa seconda categoria i resti archeologici consistono in zoccoli di muratura, limitati da pietre di agguagliamento sulle quali vengono sistemate le strutture in materiali deperibili, quali graticci o argilla pura." (Adam, J.P. 2004, 133-134). The researcher Gallina notes that the use of timber frame between 1st century BC and 1st century AD is documented in the urban and after in suburban area of Gaul Province, where it endured for a long time (Gallina, M.V. 2011, 177).

[141] "For the bracing elements to work successfully as a seismic resistant construction system they must be designed correctly, the more diagonal bracing the better. There is also an art to placing and designing diagonal bracing. The wider the base of the triangle in relation to its height the stronger it is. The diagonal should be connected to the vertical member as close to the joint with the horizontal member of the panel as possible. Since corners are the most vulnerable to damage in lateral movement, builders have positioned the diagonals there. X braces are in general stronger than diagonal bracing alone." (Doğangün, et al. 2006, 986).

[142] (Adam, J.P. 2004, 133-134)

[143] (Dessales, et al. 2014)

[144] *Chapter 2*, *section 2.3.1*

rectangular geometry, unlike the case of the medieval Portuguese dwellings and the Calabrian housings, so-called *case baraccate* (late 18th century). In the *italic domus,* the overhead light is complemented by these very small windows providing additional daylight.



Figure 1.13 – Evidence of diagonal members at *Villa di M. Arrius Diomedes* at Pompeii (© H. Dessales)

(iv) As regards the joints, it should be stressed that the analysis of ancient carpentry at Herculaneum is of utmost importance due to the scarcity of wooden components and connections in the Roman findings. However, the understanding of the original construction detail is hampered by the rough *Borbone* excavations and the heavy reconstructions carried out by Maiuri during the Fascist period.

Papaccio points out the Roman system's structural effectiveness under seismic forces.[145] On the other hand, Laumain underlines its structural fragility when compared to the medieval French timber-framed buildings. Even in the presence of a regular structural grid that allows good load distribution, the slenderness of the timber framework and the limited cross-section of the components leads us to suppose that the Romans were not aware of the potential strength of this system. The joints, fundamental for the strength of the whole building under static and dynamic loads, is not comparable to the French medieval ones; Roman architecture may be interpreted as quite humble.[146] Research on this specific topic is still required, even if some information may be deduced from other case studies in the same area: half-lap and mortise-and-tenon joints are very common (*Figure 1.14*), as shown by a recent campaign on the roof and ceiling structures of *Casa del Rilievo di Telefo* at Herculaneum[147] (*Figure 1.15*). The presence of timber connections (e.g. *cavicchi*, meaning "wooden pegs", and *zeppe,* meaning "wedge") and metallic elements (e.g. nails and iron brackets), inserted in the points where higher stresses are concentrated, are found in this example. *Trait de Jupiter* joints are also common. As Adam emphasizes, the origin of this specific joint type is the Greek shipyards tradition: the structural efficacy of these joints derives from the distribution and alternation of tension, compression, and flexion along adjacent elements.[148]

[145] (Papaccio, V. 1993)
[146] Indeed, Laumain qualifies his ideas by noting the gaps existing in the current knowledge of the half-timbered structures of Ancient Rome (Laumain, X.; Sabater, A.L. 2012, 1216).
[147] (Camardo, et al. 2015, 285-286)
[148] (Adam, J.P. 2004, 104-105)

(v) Depending on its location, thick layers covered and protected the surface wall from the effects of weather. In the case of internal walls, the surface was completely coated by painted or frescoed depictions, commissioned by the landlords.[149] Thick coats were directly applied, as the case of the 4th Style wall[150] paintings on the restored overhanging facade of *Casa di Nettuno e Anfitrite* (*Insula V,* 6-7). In the first floor of this house (rooms 15, 16), the north wall from *taberna* is plastered, according to the chromatic and composite scheme of the Fourth style decoration.

Another construction solution for the surface finish, less common and not mentioned in the excavation diaries, consisted of the wooden frames nailed on both sides with mats of entire reeds without infill. This is the same solution employed in the cladding of the ceiling, so the fragments discovered could be from both of these different construction type. As shown in the photos included in Maiuri's book, fragments with the imprint of the reeds are still visible in the timber framework walls in the courtyard of *Casa a Graticcio* (*Figure 1.16*). Even in the absence of the final layer, which testifies to the unfinished nature of the works, these traces of plain and rough materials may represent a simplified version of Vitruvius's recommendations.



Figure 1.14 – Timber frame wall at Herculaneum: detail of mortise-and-tenon joint

(© S. Stellacci, 2017)

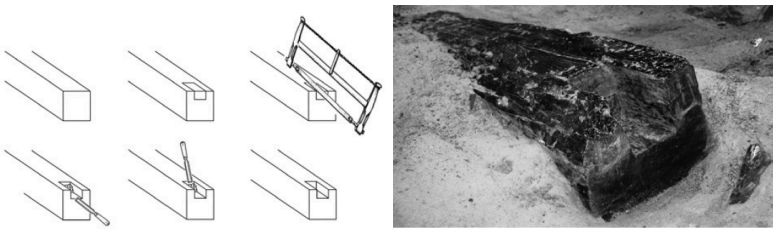

Figure 1.15 – Hypothesis of the construction phases and archeological finding (Camardo, et al. 2015, 282)

[149] (Frier, B. W. 1980, 38) *apud* (Andrews, J.N. 2006)

[150] The 4th style, prevailing after the 62 AD, is illusionistic perspective-based composition. This composite scheme recovers some aspects of the former Roman styles, the imitation of the marble facing of the 1st Style, the sense of three-dimensionality in the architectural scenes and objects of the 2nd Style, and the 3rd Style contradistinguished by sophisticated ornaments, such as candlesticks, winged figures, and plant shoots. (Andrews, J.N. 2006, vol.1, 98-99).

1.4.2 Overlapping historical layers: Casa a Graticcio (*Insula III, 13-15*)

Casa a Graticcio[151] is generally considered a remarkable result of the socio-economic organisation of the last building phase of the city, due to its specific typological and construction solutions. The importance of this case is confirmed by a detailed description ascribable to Maiuri[152] and correlated with the outstanding drawings of the architect Oliva.[153] A reference to Maiuri's intentions to describe this case in a second tome, that would never be written, also demonstrates the relevance of this case study.[154]

Catalano describes this small dwelling as *a miniature palace*; on the other hand, Maggi points out the modesty of its construction techniques and the fact of the lodgers' cohabitation in three or four units of habitation, in contrast to the esthetical values of the nearby *Casa del Bel Cortile*[155] (*Insula V, 8*) (*Figure 1.16*).

In terms of typological features*, Casa a Graticcio* represents the transition from the single-family atrium houses to multi-family houses with courtyard (*Figure 1.17*). It is also representative of humble Roman houses in the narrow hybrid *insulae* that included commercial trading on the ground floor and rental apartments in upper floors.[156] Its innovative features depend on the organization of the units around a courtyard with a *impluvium* and natural light (1.97 m x 2.97 m) – a feature that can be seen as an antecedent both for the atrium of the *Italic* house and later for the Neapolitan buildings that share the alley (the so-called *vinella napoletana*).

From the construction perspective, *Casa Graticcio* is remarkable because it is fully executed with thin partitions in *craticii*, in contrast with the massiveness of the Pre-Roman patrician housings and the brick structures of the Roman Empire.

*Casa a Graticci*o, belonging to Octavia Philadelphia, is enclosed between two Samnite houses and is adjacent to the *Casa dello Scheletro,* whose space was carved from the rear of this latter house to increase its interior space. It belongs to *Insula III* (4200 sqm)*,* which is in turn composed of six housing lots and lies between the *Cardines* (north-south streets) *III* and *IV*. This building covers a long, narrow plot and is divided into three lots on the ground level and two lots on the first floor, both supplied by independent accesses[157] (one on the *Cardo IV*, the second by an internal staircase), for a total of three (or four) units of habitations.

The first discoveries related to this case study date back to 30 August 1927,[158] during the excavations that proceeded from east to west, moving down from the upper levels: the workers entered in rooms 11 and 16 (GSEM et F) of the adjoining *Casa dello Scheletro*. The works were carried out in additional tranches until

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[151] *Casa a Graticcio* underwent a survey campaign concluded in 2003 as part of the pilot project of *Insula Orientalis I.* Public access to this dwelling was forbidden in 2016 due to the hazardous condition of its structure.

[152] The description is organized: (i) general comments on the use of *opus craticium*, (ii) facade; (iii) ground floor; and (iv) furniture (Maiuri, A. 1958, 407-420). See (Wallace-Hadrill, A. 2011, 261-271)

[153] Oliva was the official illustrator draughtsman-surveyor at Pompeii and Herculaneum during Maiuri's campaign from 1923 to the 50s. His daughter, Maria Oliva, was an illustrator in Pompeii from 1959 until 1997. Included in Maiuri's book in full or short format, the illustrations signed by Raffaele Oliva are diverse, ranging from isometric or perspective views to plants and elevations. In the case of *Casa a Graticcio*, the depiction of the materials and the detailed accuracy of these representations could indicate that the majority were drawn on-site following the restoration works (Maiuri, A. 1958, 415).

[154] (Catalano, V. 2002, 32)

[155] (Ibid., 31) (Maggi, G. 2013, 29)

[156] *Insula* IV is an exception because there the ground floors were residential in function.

[157] Of a total of ten, three original (carbonized) steps are still visible (Maiuri, A. 1958, 416)

[158] The underground tunnels were dug in this area over the late of 18th century (Catalano, V. 2002, 32). The *Borbone* damage is cited by Maiuri as cause of the original plaster lost, even if hardly plausible (Maiuri, A. 1958, 410). However, it is nearly impossible to define the exactly location of the excavations before the open-air excavation by Maiuri.

1933.[159] From the early findings it was clear that the building layout is a result of a post-earthquake reconstruction.[160] Monteix underlines the changes to the original layout through evidence of an early Samnite settlement of pre-Roman epoch.[161]

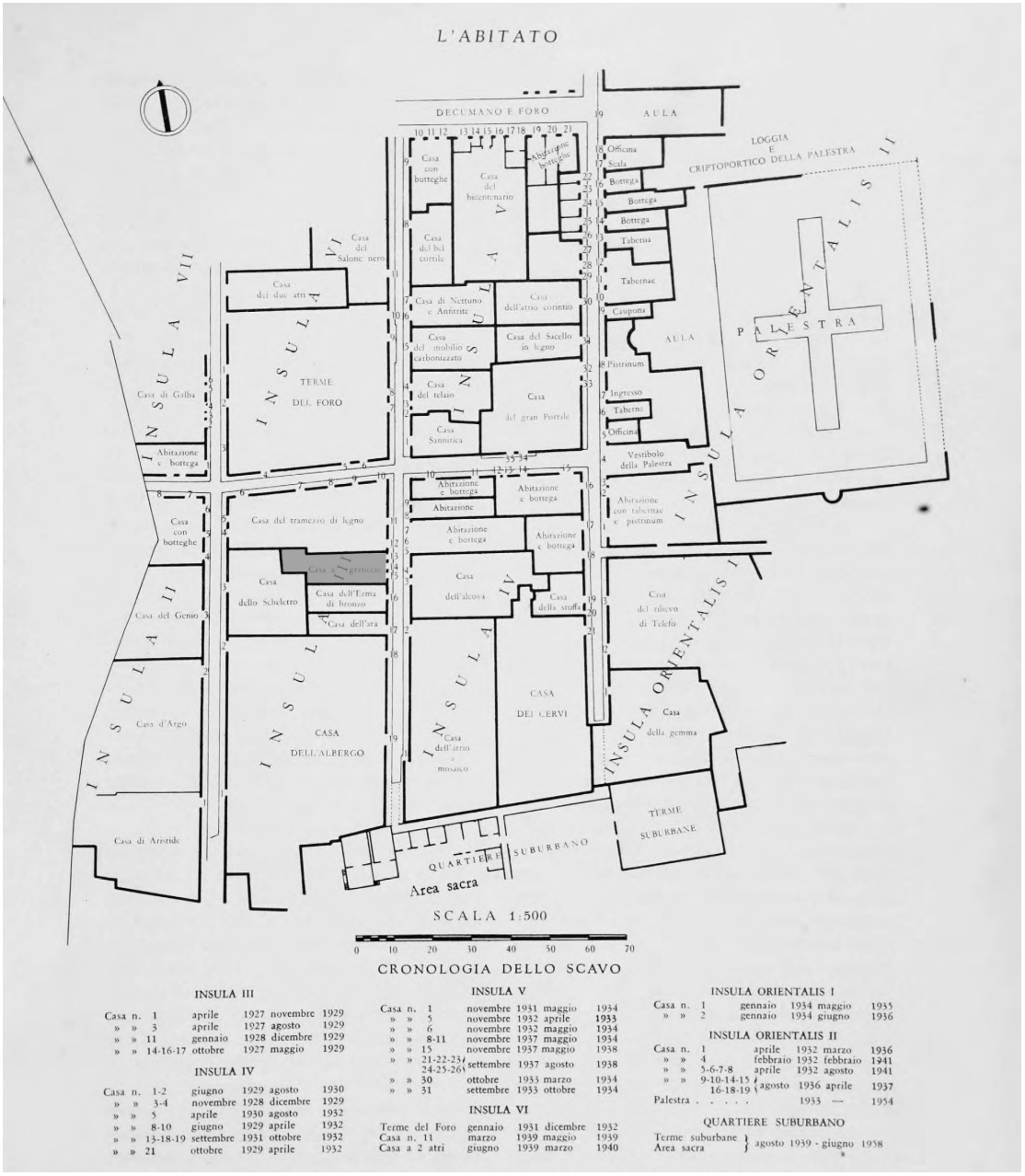

Figure 1.16 – Location of *Casa a Graticcio* (in grey) adapted from (Maiuri, A. 1958, 59)

[159] (Monteix, N. 2010, 21)
[160] (Maiuri, A. 1958, 414) (Papaccio, V. 1993, 610-611)
[161] *Casa dell'Ara*, *Casa dell'Erma di Bronzo,* and *Casa a Graticcio* probably come from a single original *domus* that was specular to the *Casa dello Scheletro* (Monteix, N. 2008).

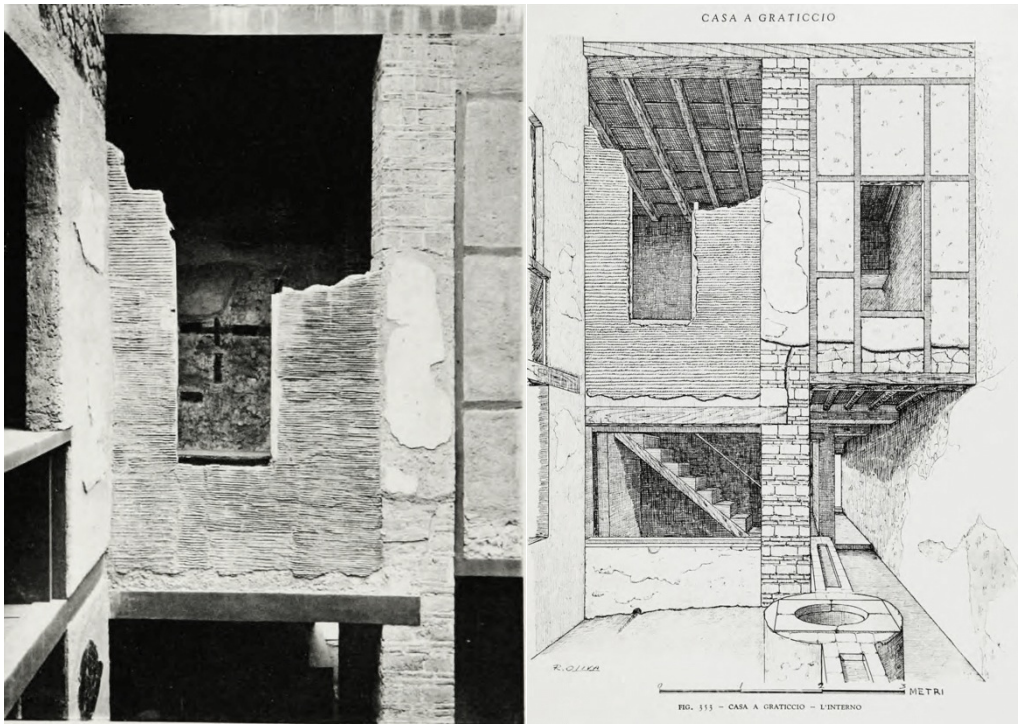

Figure 1.17 – Interior view of *Casa a Graticcio* (Maiuri, A. 1958, 409, 415)

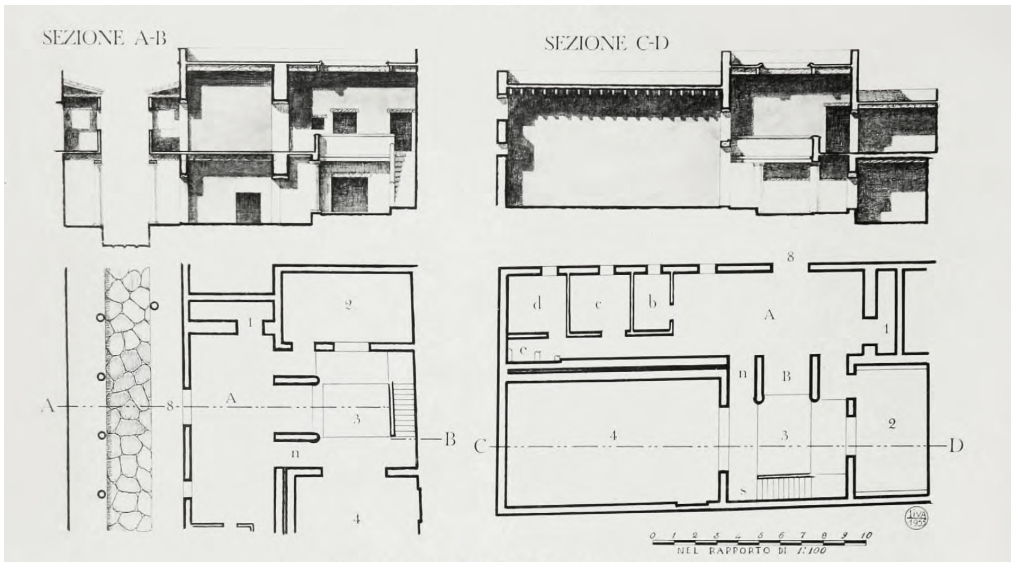

Figure 1.18 – Cross sections and plans of *Casa del Bel Cortile* (Maiuri, A. 1958, 384)

When it was discovered, only the structure on the ground floor was integrally remaining, together with two thirds of the height of the three brick pillars that were later reconstructed by Maiuri. Occupying the public sidewalk, these pillars were executed with the specific aim to support the timber floor and the upper wall, and also "to impress the status of the owner on the passer by", allowing to impress the house public sphere "beyond its usual boundaries".[162] Maiuri declares that the original timber-framed structure was conserved only on the south

[162] Balconies supported by brick columns are listed by Andrews: *Casa di Aristide*; *Casa d'Argo*; *Casa del Genio*; *Casa a Graticcio*, *Casa dell'Erma di Bronzo*; *Casa di Apollo Citaredo*; V. 25; apartment V. 26; *Casa dell'Atrio Corinzio*; *Casa del Salone Nero*; VI. 4; *Edificio sul Decumano Superiore* (Andrews, J.N. 2006, vol.1, 79).

side of the ground floor.[163]The internal walls and the external upper wall were executed using squared timber uprights, *arrectaria*, and horizontal wooden components, *transversaria,* to form 50 – 80 cm thick panels filled with rubble stones. The chosen mixed construction and architectural solutions resulted in: (i) a limited elevation (2.95 m on the ground floor and 2.90 m on the upper floor) with a consequent devaluation of the architectural proportion; (ii) small internal compartments (326 sqm divided into three lots); [164] and (iii) low ventilation, even with the synergetic combination of the benefits provided by the *maeniana* structure, the peristyle, and the lodge.

Starting with a construction analysis of the ground floor, the selection of the material components such as the *opus vittatum*[165] (also called *listatum*) responded to the requirement of protection also from intruders.[166] By being fully supported by the brick pillars, the external facade in (restored) timber framework[167] acts as a non-loading system. The structural behaviour depends also on the boundary conditions, i.e. the adjacent Samnite houses, which form a compact urban agglomeration. Due to their high flexural strength, the internal frame structures are presumed to collaborate with the external ones to support the weight of the roof structure. As underlined by Giuliani, this follows a structural model consisting of a load-bearing skeleton of linear elements appropriately spaced, which take and transfer all the stresses of the imposed loads vertically downwards.[168]

In contrast to the external wall, the internal layout of the ground floor was likely chosen for the speed of execution and low thickness of the frame system, which would have implied the possibility of easy dismantling. In its original conception, the construction system was characterised by a timber skeleton filled with *opus craticium*, the heterogeneous infill including straw, clay, and fragments of roof tiles. Divided into regular frames of 0.60 m x 0.80 m of carbonised wooden components, the framework walls were locked within pillars in brickwork or tuff rocks and brick (*Figure 1.09*).

While a question exists about the structural authenticity of this noteworthy building, that question is certainly overlooked in the literature and should be emphasised together with scepticism toward the trustworthiness of the works published by Maiuri [169] (e.g. discrepancies in the dataset and topographical references) and the didactic character of his reconstruction works. In fact, relevant incongruities can be noted from a comparison between the daybook record[170] (*Giornali di Scavo*, GSE, and *Giornali dei lavori*, GL) and the description published by Maiuri.[171] In what concerns this case study, even in the absence of a dataset from the GL report, Monteix[172] discovers several incongruities in terms of the external configuration as well as regarding items of furniture (e.g. positions of the bronze statuettes and the wooden beds in the rooms). Archive photographs allow

[163] (Maiuri, A. 1958, 410-412)
[164] Divided into access by no. 15, area 79 sqm, by no. 14 area 94 sqm, and by no. 13, area 153 sqm. The rooms are cramped (approximately of 10 sqm), poorly lit; the rooms no. 4-6 are simple field painted in Fourth style, and the other walls are rendered with plain white plaster.
[165] *Opus vittatum* consisted in a band of bricks alternating in blocks of travertine, parallelepiped in shape and horizontally arranged. The core of the walling was of rubble masonry.
[166] (Papaccio, V. 1993, 612)
[167] The main elevation is characterized by a recent box consisting of a half-timbered wall and, on the left, a wattle and daub balcony covered by an inclined roof.
[168] (Giuliani, C.F. 1990)
[169] "[L]a sua visione di Ercolano, ora condivisa, corrisponde più ad una percezione ideale e musealizzata che all'immagine emersa dallo scavo" (Monteix, N. 2008, 181). *Engl*:"[H]is vision of Herculaneum, now shared, corresponds more to an ideal, museum-display perception than to the image that emerged from the excavation".
[170] With regard to the first source, GSE, three versions were written by several researchers: the original manuscript in five volumes and conserved in the *Ufficio scavi di Ercolano* and two copies in the *Archivio storico della Soprintendenza speciale per i Beni archeologici di Napoli e Pompei* (SANP). See (Monteix, N. 2008, 181).
[171] (Maiuri, A. 1958)
[172] (Monteix, N. 2010)

interpretation of the recent works, [173] especially the one related to the reconstruction of the external wall structure and the balcony; the different phases may be identified in time through the date of the snapshot incised on the negative.[174]

The 1930s interventions on the architectural vestiges of *Casa a Graticcio* implied heavy reconstructions of the internal structures and of the volume overhanging the main street. Maiuri's dimensions for the reconstructed balcony projecting over the sidewalk are contradicted by the account reported in the daybook (i.e. a depth of 3.35 m *versus* the 1.90 m of the reconstruction). However, if the dimensions indicated in the daybook are truthful, the balcony would have extended over the road itself by 1.45 m. This projection, that allowed a significant increase area floor,[175] would have been unparalleled and excessive, in such a way as to prevent the passage of loaded wagons, thus surely illegal with regard to the Roman law principle governing land ownership, "superficies solo cedit".[176] Wallace-Hadrill suggests an alternative hypothesis, wherein the low reliability of the daybooks means that they "should be employed only with caution to confute the excavator's own account."[177]

As occurs in other buildings at Herculaneum, the type and the regularity of the replaced elements expose the modernity of this intervention[178] that aimed at a semantic unity. In addition, the high degradation of the materials induced by these improper and incompatible restoration works is clear evidence of the low authenticity of this building following its reconstruction. On the external facade, the detachment of the coating layer shows two steel beams distanced by hollow bricks that support the balcony and bear on the aforementioned pillars. The square frames of the external upper walls, whose timber components were replaced by new elements of the same size, were filled by blocks of yellow tuff stone, which is a foreign material to the local construction culture (*Figures 1.19*, *1.20*). However, even if materials similar in chromatic and chemical features had been employed, the historicity of the construction system would have prevented a restoration *à l'identique*, as Marconi states:

> "It is enough to look at any restoration *à l'identique* with expert eyes (…) to realize that the intrinsic historicity of the production processes also prevents even those who aspire with all their strength from achieving the true mimetic reproduction of anything earlier. Although the materials are the same, just the evolution of the concept of manual work from pre-modern to modern betrays (or rather denounces in no uncertain terms), the modern intervention, with the care and precision that inexorably descend from the ideological basis of work in the industrial age, which unconsciously aspires to match the accuracies of the mechanical world." [179]

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[173] The exploitation of the photographic tool for promotional purposes is clearly identifiable during this historical period. In many cases, differentiating between the physical discoveries and the restoration works is not possible based on the archive photographs, because these depict only the last phase of the intervention. These photos attractively frame the showcases of archaeological findings or the main restored elevations overlooking the sidewalks.

[174] (Monteix, N. 2008, 185)

[175] (Wallace-Hadrill, A. 2011, 262)

[176] "what is above yields to the ground" means that the air space above a public road is a public property, and it was forbidden for the private citizen to invade the road space. See (Saliou, C. 1994).

[177] (Wallace- Hadrill, A. 2014, 588)

[178] On the other hand, the *Charter of Restoration* of 1972 encouraged the use of modern materials, imported from the common site to the archaeological site.

[179] "Basterà guardare con occhi di conoscitore un qualsiasi restauro à l'identique (…) per rendersi conto che la storicità intrinseca ai processi produttivi impedisce anche a chi vi aspiri con tutte le forze, la riproduzione davvero



Figure 1.19 – Main facade of the *Casa a Graticcio* (© S. Stellacci, 2017)

In conclusion, Maiuri's reconstruction may be deemed a type of intervention that sits between conservation and innovation, or a reconstruction rather than a scientific restoration.[180] Maiuri's works do not respect the principle of scientific restoration as provided in the Italian Restoration Charter (1932), the first official directive in Italy in the field of restoration, which incorporates Giovannoni's leading principles (article 3). By this measure, reconstruction is deemed acceptable only in certain specific cases, e.g. valuable heritage destroyed by armed conflict or natural disaster. In any case, reconstruction has to be executed based on complete and detailed documentation and not on conjecture.[181] Prior to the 1930's, the structure was a witness to two historical layers: the Samnitic house (Pre-89 BC) and its post-earthquake period (from 62 AD to 79 AD). Despite Maiuri's stated aim to be faithful to "the knowledge of the structure and the sensibility of an architectonic sense", seeking the *historical truth*, his reconstruction only obscures these layers under a third of his own making. The disagreement between the objectivising approach toward restoration and the subjectivising approach of Maiuri's project is settled in this case with a clear bias towards the latter.

Leaving aside the controversial aspects the structure inherited in the 1930s, this case exemplifies the persistence of human experimentalism in the ex-post-earthquake intervention. *Casa a Graticcio* may be the most relevant example of the proactive approach to working within a project's external constrains, an attitude that has since become the basis of modern engineering.[182] The pioneering and systematic use of mixed technique (bricks, masonry stones, and timber frame walls) stemmed from the Romans' ability to structure their spaces according to the paradigms of their contemporary life.

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mimetica di alcunché di anteriore. Anche se i materiali sono identici, basterà l'evoluzione della concezione del lavoro manuale da pre-moderno a moderno a tradire (o meglio a denunciare con tutta l'esplicitezza), l'intervento moderno, con esattezze e cure che derivano inesorabilmente dall'impostazione ideologica del lavoro in età industriale, che aspira inconsciamente ad eguagliare le esattezze del mondo meccanico." (Francovich, R. 1988, 48)

[180] (Papaccio, V.; Salvatori, A. 1988, 200)

[181] (The Charter of Krakow 2000) (UNESCO 2008)

[182] (Papaccio, V. 1993, 615)



Figure 1.20 – Reconstruction works in 1929 of *Casa a Graticcio* (Monteix, N. 2010, 32)

1.5 Final comments

The persistence of the timber-framed system spans centuries and civilisations with various local declinations according to each environment. Leaving aside the debate on its provenance, it represents the most common technique among the mixed construction practices employed by Romans.

However, the archaeological evidence is scarce, especially within very strongly inhabited areas. The material is perishable and there was previously little interest in analysing and preserving these structures, as demonstrated in the destructive early excavation campaigns in the Vesuvian area (1738-1765).

The cognitive and practical phases of the archaeological site surrounding Vesuvius were analysed for the impact of seismic and eruptive phenomena on urban planning and on architectural solutions in two mid-sized towns, Herculaneum and Pompeii. Regardless their overlapping historical layers, their dwellings provide a snapshot of the ancient society and the construction processes that arose from it. They can be deemed as expression of the material memory of Roman *maeniana* (overhanging structures), the adaptation for rental purposes, as well as the distinctiveness of the decorative elements (frescoes, home furnishings).

In this framework, three main topics were briefly tackled: the difficulties of *readability* of the material traces (*sections 1.2.1*, *1.3.1*), the polysemy of the term *craticii parietes* in the ancient literature (*sections 1.2.2*, *1.2.3*), and the relationship between the technical culture and the socio-economic environment (*sections 1.3.1, 1.4.3*). Roman domestic architecture with *craticii parietes* was discussed by overlaying key factors (e.g. materials and tools, with consideration of the difficulties in gathering evidence) along two confluent pathways: from one side, through the ancient literature and the critical interpretation of it; and from the other side, through the archaeological findings from Roman urban settlements, especially in the Campania region (*section 1.4.2*).

An insight into the archaeological campaign around Mount Vesuvius sheds some light on: (i) the involvement of *Borbone* courts in 18th century, during the same period of post-earthquake reconstruction of the Calabrian centres; (ii) and the tangible evidence of the *opus craticium*. Thus, two specific periods of Herculaneum excavations are examined: the first phase (1738-1765) and the early period of the Maiuri's campaign (1927-1961).

With regards to the first mentioned phase, the figure of La Vega (1737-1804) stands out as one of the parties responsible for the key events in the late 18th century: the underground excavations (*cunicoli borbonici*) and the rebuilding of Calabrian towns thirteen years later.

Turning to the second phase of excavations, the efforts to reveal the Roman remains by the Maiuri team leaves us precious yet controversial physical evidence, such as *Casa a Graticcio* (*Insula* III, 13-15). Its speculative reconstruction, often overlooked in the literature, is discussed to raise issues related to its value, conservation, and public appreciation.

The archaeological findings clearly show that Romans developed an empirical understanding of the principles of dynamics, probably based on post-analysis of the seismic damage. However, timber frame walls in the Vesuvian area dated back before the 62 (or 63) AD earthquake, as testified by the partitions at Herculaneum in *Casa del Bicentenario* (rooms 48-49) decorated with paintings of the Fourth Style, in the rich summer *triclinium* of *Casa di Nettuno e Anfitrite*, and in the partition of *Casa del Moralista* at Pompeii, whose frescos date back to the late Third style (2nd quarter of the 1st century AD) with traces of earlier plasters.

Between the Augustan Age and after the 62/63 AD earthquake, the strong demand of new constructions and the need of their heavy repairs may have influenced the diffusion of flimsy timber-frame walls, foremost within the private buildings at Herculaneum. After seventeen years of the mentioned earthquake, the anaerobic

conditions resulting from the specific on-site burial (79 AD) led to the conservation of the timber structural elements, leaving a fragile legacy to be revealed by the new generation of archaeologist.

Herculaneum's physical evidence of *craticii parietes*, even if heavily damaged by the *Borbone* tunnels and later altered by the works of the 1930s, has proven that the greatest reason underpinning their use is likely to take advantage of a swift solution that allowed a more spatial flexibility rather than to achieve a load bearing and not so an anti-seismic resistance. The self-supporting performance and the possibility to split the interior space by optimizing the available area without significant physical constraints or to add extra space by light overhangs of upper floors are the main benefits of their use. The hypothesis that weigh-saving prevailed to other considerations can be supported by fact that the timber framework was found as simple partitions at every level – in places that were not directly supported by walls below – and as the external facade on the upper floors supported by brick pillars. Traces of fine paintings[183] and valued furniture bear witness to the high economic value of rental spaces at this time, obtained precisely by the execution of thin partitions in *craticium* by landlords. It should be noted that the series of well-fitted apartments on upper floors – those extensively analysed by Andrews –[184] would not match with the common idea that the timber frame walls were employed in order to skimp on construction costs. This is even more evident in the majestic public building of *College* or *Shrine of the Augustales* (VI, 21), where the timber frame wall was erected in a second phase to bound the custodian's room at the end of the right hallway.

The wooden skeleton with square frames is also employed in the humble *Casa a Graticcio* (*Insula III*, 13-15). The process that transpired from the discovery of this house in 1927 to its current appreciation is reviewed in this research, grounded on a recent literature review related to the archival dataset and on an on-site analysis, with the aim of analysing the influence of the timber framework on the overall building behaviour. As stated by Maiuri: "[t]his is the first attempt to employ the primitive timber structures of the Italic rural house for the urban development of a city."[185] On a closer look, wooden beams support the external timber frames walls, whereas the main structural role is demanded to the boundary conditions, i.e. the brick pillars on the ground floor and the adjacent constructions. It is also shown that technical solutions converge in *Casa a Graticcio* in order to solve different requirements, such as the residential pressure, fast reconstruction, and cost-effectiveness, while we can supposed that we are still conceptually distant to the attribution of a earthquake resistant role to a timber framework.

Finally, it should be added that a comprehensive understanding of the ancient urban setting is precluded for us, since the extreme disruption of the Vesuvian towns and ineffective restoration practices (e.g. *Casa d' Argo*) have deprived us of the main architectural and structural features. For this reason and due to the incompleteness of the underground excavations, many questions about the timber-framed walls still remain unanswered.

In the next chapter, the analysis of the physical evidences of timber-framed structures shall be unfolded a significant chronological jump in the Middle Ages.

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[183] Evidence of paintings provides an insight into the original domestic environment, whose features would have not been fairly different from those of the ground floor (Andrews, J.N. 2006, vol.1, 100).

[184] (Andrews, J.N. 2006)

[185] "[è] il primo tentativo di applicare le strutture primitive lignee della casa rurale italica allo sviluppo urbanistico d'una città." (Maiuri, A. 1958, 74)

SECTION 2: A diachronic analysis of historical timber-framed dwellings in Portugal and in the South of Italy



CHAPTER 2 – Physical and technical continuities in the 1755 post-seismic reconstruction of Lisbon

2.1 Introduction

> "A century never starts on the first day of its calendar and ends on the last. Depending on how its interior is divided, it can be recounted in different ways. Separating the flow of history into periods, saying when and how each starts and ends and when and why, telling the main features, is a way of thinking about the time, trying to re-build the sense of its flow."[1] (Secchi, B. 2008)

> "The existing monuments form an ideal order among themselves, which is modified by the introduction of the new (the really new) work of art among them. The existing order is complete before the new work arrives; for order to persist after the supervention of novelty, the whole existing order must be, if ever so slightly, altered; and so the relations, proportions, values of each work of art toward the whole are readjusted; and this is *conformity between the old and the new*." (Eliot, T.S. 1921, 44-45)

Since ancient times , the genesis of human settlements has been strongly influenced by the preference for local materials from nearby supply areas and from sites where different geological zones meet.[2] Wood, together with clay (or raw earth) bricks, mortared stone infill or rubble masonry, are the primary construction materials for "objective reasons", as defined by Paolo Maretto, i.e. local resources, cheapness, scale of application, and environmental – physical and civil – constraints.[3]

However, the logic underpinning the development of settlements and the permanence of construction solutions in time can be fully understood also as a reaction to unexpected factors, including damage caused by natural disasters. Regardless of factors that distinguish the traditional systems (e.g. their large differences owed to a territorial multiplicity[4] and their high perishability) and the limited technical knowledge (not full awareness of the mechanical strength of these systems), empirical construction practices have embodied anti-seismic devices for many centuries. In Portugal and also in other seismic-prone zones, local communities have defined building techniques able to counteract and metabolise the shearing actions.[5] Among many techniques, probably the most reliable system is based on load-bearing vertical timber structures filled and interlocked with the other buildings

[1] "Un secolo non inizia mai il primo giorno del suo calendario e non termina l'ultimo. A seconda di come il suo interno viene diviso, può essere raccontato in modi diversi. Separare il fluire della storia in periodi, dire quando ciascuno inizia e come e quando termina e perché, raccontandone i caratteri principali, è un modo di pensare il tempo, di ri-costruirlo cercando il senso del suo fluire."
[2] (AA.VV. 1980) (Oliveira, E.V.; Galhano, F. 2003, 361-362)
[3] (Maretto, P. 1993, 99)
[4] Different artefacts in terms of type, shape, and material have been fostered over the centuries by a territorial pluralism – depending on lithological and climatic factors – in Portugal and in Italy.
[5] (Correia, M.; Lourenço, P.B.; Varum, H., eds. 2015, 71)

components. Because a strict relationship between the seismic damage and the following reconstruction activities has found an incontrovertibly similar response in different contexts (e.g. in Portugal and in Italy), the respective common antecedents at urban and architectural scales shall be examined below and in the next chapter. It encompasses the research foci of the "conformity between the old and the new", in Eliot's words.

Seeking prior technical evidence of the seismic local culture in Portugal and in the South of Italy has opened multiple paths of research in which building practices are still unexplored and overlooked in the literature. Although several researchers have noted the existence of an empirical ancient seismic culture within the Mediterranean civilisations[6] (and not limited to them), few on-site case studies can be counted.

As a comprehensive study of the antecedents exceeds the scope of this research,[7] the author of this thesis shortens the points of this analysis by discussing only some of physical evidence in Lisbon prior to the great earthquake of 1755 (*Figure 2.01*) and comparing it with the 18th century buildings of the rebuilt centre.

The Medieval and Renaissance ordinary buildings in the downtown Lisbon that contributed to the makeup of a *Global City*[8] shall be examined as both *artefacts* and *events*, if we evoke Tafuri's thought – as stated by Biraghi: "The physical space that until then was characterized in a certain way *differs* from the previous state after the "'happening' of a new building".[9]



Figure 2.01 – Lisbon view pre- and during the earthquake, etching by M. Sautter (18th century), Museum of Lisbon

[6] (Gülkan, P.; Langenbach, R. 2004) (Dutu, A.; Ferreira, G.F.; Guerriero, I.; Branco, F.; Gonçalves, A. 2012) (Correia, M.; Lourenço, P.B.; Varum, H., eds. 2015, 67-76)

[7] A line of further research could be the technical influence from Northern Europe (e.g. Flemish or Dutch areas) to Lisbon, and generally to the mainland, cited by several scholars (Santos, N.B.; Cunha, R.M.; Alves, R.R.; Rodeia, T.B. 1993, 15-16), but as yet not fully discussed.

[8] (Gshwend, A.J.; Lowe, K.J.P. 2015)

[9] "Lo spazio fisico che fino a quel momento era connotato in un certo modo, *differisce* dallo stato precedente in seguito all'evenire di un nuovo edificio." (Marino, O. 2009, 21)

2.2 Planning models and practices of ordinary timber-framed buildings in pre-1755 Lisbon

In the pioneering research published in 1965, *Lisboa Pombalina e o Iluminismo*, José-Augusto França identifies three key points in the urban history of pre-1755 Lisbon – "a city of medieval structures inhabited by a court of baroque taste",[10] each contradistinguished by specific artefacts: first, the allotment in *Bairro Alto* (*High District*) from the 1510s; second, the elegant tower with square dome designed by the Italian architect Terzi (1520-1597) to embellish the Royal Palace of the Riverside district (*Paço Real da Ribeira*), whose construction was started by King Manuel in 1498; [11] third, *Águas Livres* aqueduct (1696-1763), which along with other important monuments (including public fountains) saw the involvement of the military officer Mardel under the prosperous reign of João V (r. 1706-1750).

The first of these episodes anticipates the rational pattern that would later characterise the strategic planning model of downtown Lisbon. Insight into the *Bairro Alto* allotment is provided in Hélder Carita's broad, attentive reading on matters of central policy management before and during the *Manueline* epoch (r.1496-1521).[12] The city layout model in Portugal during the early 16th century, arising from the set of municipal regulations for the standardisation of buildings and their components, was substantially far from the previous Moorish paradigms and later coming to reflect the cultural influence of the Italian treatises.[13] It constituted the basis of the Portuguese planning models in the mainland and overseas during the Age of Discovery. The joint effort of the Portuguese crown and councillor for imprinting urban regularity through the alignment of the building plots and widening of the streets epitomized "a global extemporal idea of modernization", as evidenced by Rossa's studies.[14] The second episode regards Terzi's tower, whose view was open towards overseas routes. It influenced the composite scheme of future buildings, ranging from the architectural complex in Mafra – as conceived by Ludovice[15] – to the entire *Pombalino* building stock, although streamlined in its architectural scheme and details. Moreover, the majestic *Águas Livres* aqueduct, whose 109 gothic arches were built between 1729 and 1748 by Manuel da Maia, is viewed in literature – together with the Palace in Mafra – as the most important construction in Portugal for its impressive size, architectural consistency, and for the efficient worksite activities that involved a large number of craftsmen and engineers.

Each according to its own features, these three significant episodes – whose detailed analysis is beyond this research, since they are extensively discussed in literature – should be understood as physical and technical legacies that laid the groundwork for post-1755 Lisbon. A set of municipal regulations, which had also matured in the Portuguese Overseas Empire over the centuries, was thus crucial for the definition of Lisbon's new layout, whose features materialised under the enlightened despotism of minister Sebastião José de Carvalho e Melo,

[10] "uma cidade de estruturas medievais habitada por uma corte de gosto barroco" (França, J. A. 1987, 12)
[11] (Kubler, G. 1972, 76-87)
[12] The main principle of the urban planning of *Bairro Alto* was itself anticipated by the nearby allotment in *Bairro da Pedreira* (Quarry District) of the 14th century, with the new layout of secondary streets orthogonal to a main central axis – later described as an "embrionic herringbone" structure (Carita, H. 1999, 36-37, 39). See also (Cabrita, A.R.; Aguiar, J.; Appleton, J. 1992) (Carita, H. 1994).
[13] As foreseen in literature, during the Renaissance the Portuguese planning model was affected by a cultural influence of Italian treaties: Teixeira and Valla refer to a knowledge dissemination in Portugal of *De Re Aedificatoria* by Alberti (1452), and the *Trattato di Architettura Civile e Militare* by Martini (1495). The scholars refer also to the Vitruvius *De Architectura* translated by Pedro Nunes in 1541 and, in the same year, the *Book IV* of *Regole Generali di Architettura* offered by Serlio himself to Francisco de Holanda (Teixeira, M.C.; Valla, M. 1999, 83-84) (Rossa, W. 2015, 311).
[14] (Rossa, W. 2015, 375)
[15] (França, J. A. 1987, 30)

better known as the Marquis of Pombal. His wielding of power in the aftermath of the earthquake, which occurred five years into José I's reign, was so fundamental that this historical phase and its multiple products are labelled *Pombalino*.

2.2.1 (Out)line of main road axes and regular allotment of Bairro Alto

Lisbon's medieval settlement, whose environment was originally demarcated by the *Cerca moura* (Moorish Wall) perimeter,[16] was characterised by the compact pattern of a highly irregular mass of dwellings.[17] Today's observer cannot conceive its contours by any stretch of imagination:

> "In order to have an idea of what the urban compound of the city of the Tagus would have been in the first quarter of the 16th century, you have to close your eyes, forget the whole current physiognomy, and open them, in an imaginative effort, toward an interior vision in which the suggestions of the unruled streets, the unforeseen and the whites of Alentejana Évora have to intervene [.] Form, colour, movement, shadows, construction imbalances in the architectural masses, the constant breakdown of the alignments, on top of which the population, in polychromatic contrast, passing through back doors – everything was totally different from now."[18]

The irregular configuration of the settlement in Lisbon was strongly influenced by its topographic morphology: "The ideal Roman urban layout embodied an ippodameo plan, crossing the streets at right angles, defining identical blocks (...). In the Olisipo urbs, the topography made orthogonal planning impossible, which the pre-Roman layout also complicated."[19]

However, a concern for regularity of the street width underpins some provisions, those related to the construction of a city wall by King Dinis (r.1279-1325) and the enlargement of *Rua Nova*, works that caused the demolition of some buildings in 1294 for aesthetic and functional reasons. Similarly, the street parallel to the Tagus riverfront, *Rua dos Ferreiros*, and the reconfiguration of the nearby *Largo dos Açougues* were executed in the following year in compliance with legal concerns.[20, 21]

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[16] The urban and non-urban areas were not physically separated in Lisbon, as early as 1147 three neighbourhoods were settled outside the Moorish wall and this situation demanded the construction of the *Dionysian* (1295) and *Fernandine Walls* (1373-1375) (Silva, C.G. 2008, 22-23).

[17] Insights into the medieval settlement system of Lisbon are provided by Augusto Vieira da Silva and later by Irisalva Moita (Silva, A.V. 1939) (Silva, A.V. 1940) (Moita, I. 1983); additionally other recent scholars referred by Carlos Guardado da Silva, among which Vasco Gil Mantas and Guilherme Cardoso (Castelo-Branco, F. 1990, 97-104) (Farinha, J.S.B. 1997, 7) (Silva, C.G. 2008, 35). See also (Araújo, N. 1938).

[18] "Para se ter uma impressão do que seria o aglomerado urbano da cidade do Tejo no primeiro quartel do quinhentismo, há que fechar os olhos, esquecer de todo a sua fisionomia de agora, e abri-los, num esforço de imaginativa, para uma visão interior em que as sugestões das ruas indisciplinadas, dos imprevistos e dos brancos da alentejana Évora têm de intervir [.] Forma, cor, movimento, sombras, desequilíbrios construtivos nas massas arquitecturais, a quebra constante dos alinhamentos, isto à parte a mancha populacional, num contraste de policromias, escorrendo pelas serventias, tudo era totalmente diferente de agora." (Sequeira, G.M. 1959, 115)

[19] "O traçado urbano romano ideal tinha planta hipodâmica, cruzando-se as ruas em ângulo recto, definindo quarteirões idênticos (...). Na urbs de Olisipo, a topografia tornava impossível um planeamento ortogonal, que o traçado pré-romano também dificultava." (Silva, C.G. 2008, 42)

[20] AN/TT, Chancelaria de D. Dinis, livro II, fl. 81-v and fl. 99-v mentioned by (Carita, H. 1999, 33, 45).

Densely packed timber-framed dwellings were built and re-built, shaping the tangle of sloping streets and winding alleys. Wood prevailed in ordinary buildings: exterior planks and *mucharabiés* (shutter), floors and ceilings, the skeletons of interior partitions, and external load-bearing walls. These latter were commonly viewed as humble and unsafe structures due to their high ignitability and decay. The use of exterior timber frame walls conflicted with the public purpose of embellishing the urban image, for which stone was preferred, especially on the main streets. However, the typical medieval archetype of multi-storey timber-framed construction, arising from former habits and traditional construction techniques, is also fundamental for the configuration of the modern *urbe*, as detailed below.

Regardless of a general reluctance to change old habits, as well as Lisbon's environment and its historical constraints – slope steepness and pre-existing constructions, considerable efforts were made to improve the medieval urban structure through *Cartas Régias* (1499-1502), legislative regulations issued by King Manuel I (r.1496-1521). In fact, this code forbade all large overhangs due to transit problems and fire hazard, and it ordered the destruction of all large timber balconies[22] within a period of six months; noncompliance was punishable by fine. In particular, this code prohibited wood in the external walls and limited overhanging volumes to one and a half palms.[23] Accordingly, flat and aligned facades (made of stone masonry and lime mortars) were ordered to replace the cantilevered volume in timber frames.[24] By the end of the 15th century, the overhanging volumes were allowed if they occupied less than one third of the street width – a measure that included the edge of the roof[25] – as imposed in the *Livros das Posturas Antigas* [26] (*L.P.A.* hereinafter). It was therefore possible for only one third of the street to remain open, with this exception: if there was a sole proprietor, the connection of two frontal buildings by a single structure, so-called *passadiços* (footbridges), was allowed.[27] However, in this case, the owner's right was compromised due to the possibility that they could be demolished by public authority. The medieval law allowing the overhangs was revoked in 1499, and the new houses had to be built with a straight wall (*parede direita*). [28] In 1502, King Manuel I ordered the demolition of several houses that hindered access to the Royal Palace and to the church Sé (the cathedral). He also deplored the buildings' wooden external walls and established that their repair or replacement (with bricks walls) should be done within just one year at most.[29] Other provisions aimed to solve sanitation issues and traffic congestion, daily problems that worsened for example

[21] In Italy, a sort of urban rationality distinguishes medieval urban planning, albeit with differences in each settlement. Some examples of virtuous reaction to high demographic pressure can be found in Siena in 1222, when the building regulation imposed straight disposition of the constructions ("a corda e recta linea"), and in Brescia in 1237, when friar Alberico da Gambara promoted urban expansion along regular streets by estabilishing a set of codified rules for the expropriation of the existing houses (Le Goff, J. 1982, 53).

[22] Archival documents cited by Carita (Carita, H. 1994, 17): AH-CML, *Livros dos Reis - D. Manuel I*, livro 1.º, Doc.38 (Lx., 17-6-1499), doc.70 (Lx., 10-2-1502), doc.75 (Lx.,3-4-1502), doc.82 (Lx., 10-8-1502). See footnote 23.

[23] AML-AH, *Livros dos Reis. D. Manuel I*, doc. 75, fl. 58v-59 provision of 3 April 1502 (*Alvará del-Rey a Câmara porque manda que não haja balcoens nem sacadas não mais que a Rua Nova*) published by (Carita, H. 1999, 219); AML-AH, *Livros dos Reis. D. Manuel I*, doc. 75, fl. 63v-64 provision of 10 August 1502 (*Alvará porque El-Rey manda que não todos os balcoens da cidade se derribem e somente fiquem os conque diz pensar e od que não passarem de dous palmos*), published by (Carita, H. 1994, 223-224).

[24] AML-AH, *Livros dos Reis. D. Manuel I*, livro 1º, doc.82.

[25] Beyond the specific urban configuration influenced by recesses and overhangs, what is important to underline in this context is that large balconies or structures can increase eccentricity of the loads: heavy stone slabs, placed without proper connections to the external wall, can set up side-shift mechanisms under cyclic loads.

[26] *Book of Secular Positions of Lisbon* (CML 1974, 107)

[27] (Gonçalves, I. 1986, 156-158)

[28] *Documentos do Arquivo Histórico,* AML-AH, doc.38, fl.32-32-v, page 53,17 June 1499, transcribed by Carita (Carita, H. 1999, 214).

[29] (Gonçalves, I. 1996, 93)

during the *Corpus Christi* procession.[30] To this end, the removal of balconies, outposts, and any overhangs in the streets was imposed. A new urban architectural model, characterised by simple aligned volumes, regular fenestration, and absence (or reductions) of any overhangs and balconies, materialised during the *Manueline* epoch. Two-storey buildings in stone masonry and lime became the archetype imposed by *Câmara Real* of the pre-modern epoch, replacing the house with high facades implanted on a narrow plot.[31]

Besides the effects of the *Cartas Régias* on the Lisbon settlement, two other crucial urban points in Lisbon deserve a brief glance of their own; these are: *Rua Nova*[32] *dos Mercadores*, the main road axis on the alluvial plane, 8.80 m in width and running for 286 m,[33] and a regular building pattern, *Vila Nova de Andrade,* as the result of a private initiative for financial profit.

The Tagus waterfront around *Rua Nova dos Mercadores* has been densely populated since the 12th century,[34] when the Portuguese overseas territories played an increasingly important role, as demonstrated by the erection of four churches at lowest plane of the city over only a few decades (churches of *Madalena*, *de São Nicolau*, *de Santa Justa*, and *de São Julião*).[35] The commercial and amministrative core of the city gravitated around two streets parallel to bank of the Tagus – *Rua Nova dos Mercadores* and *Rua dos Ferreiros* – and around the *Largo dos Açougues* (later *Largo do Pelourinho*, Widening Pillory).[36] In line with the Roman roads system, *Rua Nova dos Mercadores* would be the *decumanus*, while *Rua Nova d'El Rei*, renewed by King Manuel I, would be the *cardus*, which allowed a direct connection between *Rossio* and *Ribeira*.

Rua Nova, with its irregular wide street landscape, was in contrast with the typical narrowness of the medieval streets. In fact, Lisbon's medieval streets measured generally from two to six meters, with even a few of just one meter, while their irregular winding paths were necessary for overcoming the significant natural height differences.[37] *Rua Nova* ran diagonally between the corners of the present-day streets *Rua de São Julião* and *Rua do Comércio*, on one side, and *Rua do Ourives do Ouro* and *Rua dos Fanqueiros*, on the other side. The regularization of its path, its elongation towards the western side, and its paving were performed under Dinis I's reign.[38] As shown by two 16th century paintings acquired in 1866 by Dante Gabriel Rossetti, a pre-Raphaelite painter, this was the most bustling street of the city, a favoured place for workshops of jewelers, engravers,

[30] (Barbosa, J.M.S.P. 1993, vol.1, 120) *apud* (Teixeira, M.C.; Valla, M. 1999, 83)
[31] (Carita, H. 1999, 198)
[32] The adjective *new* embodied the modern spatial paradigm. The street was viewed as an entity characterized by its beginning and end, with a tight sequence of building facades. This idea contrasts with traditional toponomies, which were related to specific physical artefacts (churches, convents) or working activities (Carita, H. 1999, 29).
[33] (Gshwend, A.J.; Lowe, K.J.P. 2015, 110)
[34] Important in the devolopment of the Roman *urbis*, this area alongside the Hill of the Castle was marked by fishing activities, with evidence of fish-salting factories having been uncovered in arteries near the *Rua dos Fanqueiros*, in *Rua dos Douradores*, *Rua dos Correeiros*, and *Rua Augusta* (Bugalhão, J.; Sabrosa, A. 1995), (Diogo, A.M.D.; Trindade, L. 2000) (Bugalhão, J. 2001).
[35] (Carita, H. 1999, 21) (França, J. A. 2008, 72-73)
[36] (Carita, H. 1999, 30-35)
[37] (Gonçalves, I. 1996, 81-82) (Rossa, W. 2002, 224)
[38] On the basis of a contract between the King and the fishermen from Cascais, *Rua Nova* was likely made of flagstone of 0.60 x 0.30 m in a strip close to the dwellings, and the other part measuring 3 x 1.5 palms covered in pebbles (D.A.H.C.M.L. vol. IV, P.341) (Gonçalves, I. 1986, 168).

goldsmiths, and gilders, as well as for barter houses[39] (*Figure 2.02*). It also became the reference model for other arteries, such as *Rua da Tanoaria*, that had not yet been laid.[40]

In addition to the enlargement of *Rua Nova*, another clear example of the urban renewal is represented in the 15th century allotment in *Vila Nova de Andrade*, better known later as *Bairro Alto de São Roque*. Its parcelling out and construction can be divided into three chronological phases that proceeded from south to north and whose physical demarcation lines are respectively the ancient streets *Estrada dos Santos* and *Travessa da Queimada* (*Figure 2.03*).



Figure 2.02 – Anonymous Netherlandish artist, View of the *Rua Nova dos Mercadores* in Lisbon, oil on canvas (ca. 1570-1619), The Society of Antiquaries, Kelmscott Manor, Oxfordside (inv. nos. KM 186.1, KM 186.2) (Gshwend, A.J.; Lowe, K.J.P. 2015, 23)

In contrast to the uncontrolled population growth in Lisbon, the urban pattern in *Vila Nova de Andrade* within rectangular or trapezoidal quarters can be interpreted as a pioneering urbanisation model in the city until then.[41] França outlines the importance of this urban episode, defining it as a proto-grid layout and also emphasising the Spanish influence:

> "Bairro Alto marks the transition from the sixteenth to the seventeenth century in the urban life of Lisbon, and the acquisition of an urban planning and architectural awareness that was gained throughout the sixteenth century, starting from and largely thanks to the Spanish occupation that the influence of the Castilian civilization brought to the Portuguese capital at the time when the great architecture of the Century of Gold was developing."[42]

[39] The canvas was later divided into two by Rossetti to fit into his house, the identification of the city – depicted in an everyday scene – was set up in 2009, by Annemarie Jordan Gschwend and Kate Lowe (Gshwend, A.J.; Lowe, K.J.P. 2015).

[40] (Silva, A.V. 1940, 98) (André, P. 2015, 83)

[41] The 16th century interventions can be divided into several categories (i.e. fortresses, urban renewals including the execution of new squares, new blocks, and settlement from scratch), among which *Bairro Alto* in Lisbon, Angra, and in Braga are addressed in literature (Teixeira, M.C.; Valla, M. 1999, 27, 83-90) (Rossa, W. 2015, 375).

[42] "O Bairro Alto marca a passagem do século XVI para o XVII na vida urbana de Lisboa, e a adquisição de uma consciência urbanística e arquitectónica que ao longo de Seiscentos se processou, a partir e em grande parte graças à ocupação espanhola que trouxe à capital portuguesa a influência da civilização castelhana no momento em que nela se desenvolvia a grande arquitectura do Siglo d'Oro." (França, J. A. 1980, 24)

The large tract of land originally belonged to a Jewish court astrologer and surgeon, Guedelha Palançano, whose widow sold it to Andrade's family shortly after 1487.[43] In this district, the early building phase (after the 1531 earthquake) was probably linked to fishing activities due to the proximity of the river, whereas the latter phase revolved around the *São Roque* church following the arrival of the Jesuits in 1553. As testified by the execution of some palaces and convents in this area, this latter stage also featured the presence of well-off inhabitants.

The *Vila Nova de Andrade* allotment had to be executed within a limited period of three years in compliance with a recent legal provision of the time.[44] In both socio-economic and architectural spheres, the modernity of *Vila Nova de Andrade* is more easily legible in the last two construction stages for the following reasons: (i) increased social cohesion between the earlier residents and a wealthier class of new inhabitants; [45] (ii) maximum exploitation of the buildable lands; (iii) concern with the spatial (i.e. visual) impact of the layout prioritized over the functional programme once predominant in the medieval settlements; (iv) absence of overhangs or significant irregularity in the geometry of the buildings; and (v) recourse to a module corresponding to a double square building plot called *chão*, a medieval agrarian unit of measure equal to 60 x 30 palms (13.5 m x 6.75 m).[46]

It is not surprising that the lot's dimensions bear on the geometry of the wooden components, which the central authorities strove to rationalize and harmonize in this period. Each rectangular block was composed of 14 lots: two rows of 7 back-to-back, facing their respective streets. One consequence of this more efficient use of the available land was that backyards with rear external annexes – typical of medieval neighbourhoods[47] – were omitted. The newly modern layout impacted the dwellers' lifestyle, eliminating the open space, which previously accommodated activities from rural memory (e.g. related with agriculture and domestic animals). The medieval spatial configuration, structured with a hierarchical yet irregular sequence of facade streets and back streets, was completely lost, and the building block itself gained meaning.

This set of principles for spatial arrangement (the enlargement and regularization of the street, the rationalization of the allotments) and the architectural scheme (the recourse to the unit module and its sub modules,[48] the regularity of the openings, the straight angle of the jambs) would converge in the configuration of the *central chessboard*[49] of the new Lisbon.

[43] (França, J. A. 1987, 27) (Cabrita, A.R.; Aguiar, J.; Appleton, J. 1992, 34) (Carita, H. 1994, 19) (Teixeira, M.C.; Valla, M. 1999, 91)
[44] (Carita, H. 1994, 48-49, 111)
[45] This allotment embodies regular solutions that can be deemed isomorphic of the social relationship of dependence (Portas, N. 2005, 52).
[46] This allotment upholds the hypothesis of a coexistence of execution practices in Lisbon derived from different models – Islamic versus Western – where *Vila Nova de Andrade* is representative of the second (Carita, H. 1994) (Rossa, W. 2015, 75).
[47] One of the most typical features was the presence of un-built interior spaces, as represented by George Braun and Franz Hogenberg in *Civitates Orbis Terrarum* of 1594 (Trindade, L. 2009, 103).
[48] The module employed in the later phase (1627) differs from those used in the aftermath of the 1755 earthquake. Thus, the post-earthquake rebuilding in this district, carried out by small-sized builders, which convey empirical ancient knowledge, adapted itself to the pre-existing small lots and not vice versa (Carita, H. 1999, 60).
[49] "tabuleiro central" (Barreiros, M.H. 2013, 26)

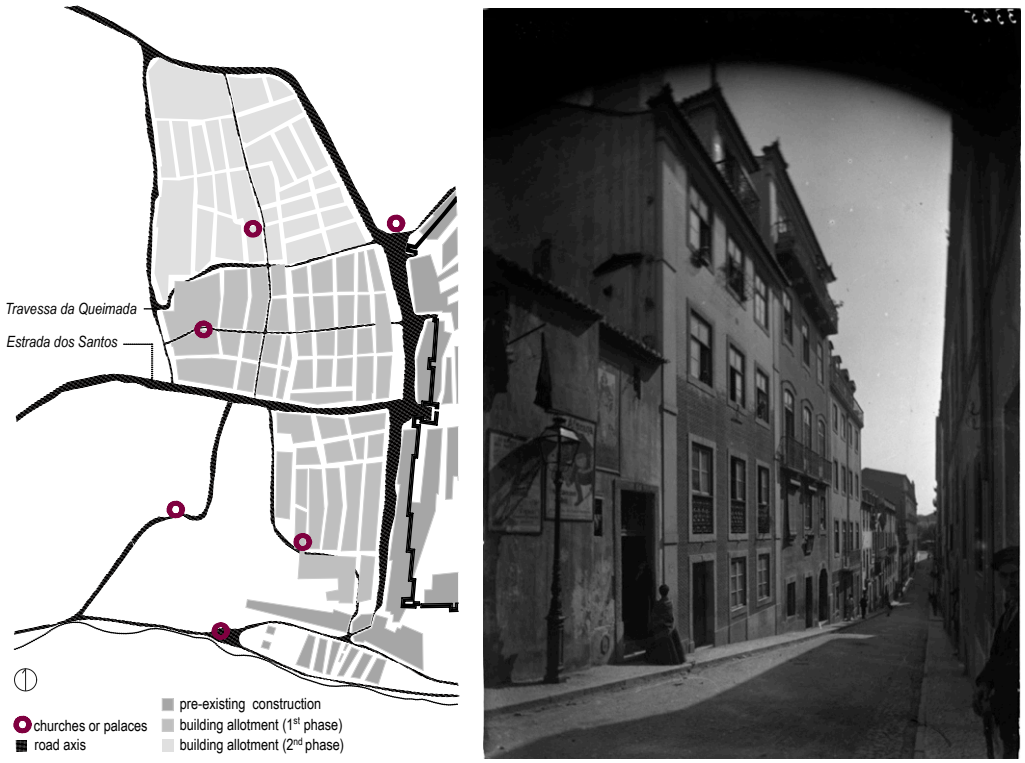

Figure 2.03 – (left) Allotment plan of *Vila Nova de Andrade* district in Lisbon (© S.Stellacci); [50] (right) *Travessa da Queimada* (photo by Machado & Souza, from 1898 to 1908, PT/AMLSB/CMLSBAH/PCSP/003/FAN/003325)

On the other hand, Portas identifies a substantial difference between *Bairro Alto* and the downtown Lisbon rebuilt after the earthquake, where "the layout of public space is not employed as simple support of an open and adaptable system to future alterations of typology and taste of building, but as one huge unified object".[51] Additionally, the scholar underlines other analogies between reconstructions of the late 17th to 18th centuries and following extensive urban planning; looking at the urban renewal under the direction of minister Duarte Pacheco (1900-1943), what is common with the late 18th century planning is the role of the central authorities, which acted as agent of the for-profit transfer and with the aim to reinforce the support to a fraction of the ruling class.[52]

It is reasonable to expect that even in the absence of a seismic event, the regularity of the road system and the alignment of the building facades would sooner or later have been extended to the lowland area of Renaissance Lisbon to cope with transit problems. In compliance with the Decree law of 13 Abril 1745, the width of all main streets should have been enlarged to 40 palms or to 20-25 palms, as occurred in *Rua da Correaria* and in *Pedras Negras.*[53] Such a plan was at the time constrained by economic feasibility; the public coffers wouldn't have been able to cover the high expense of owners' expropriations.

[50] *Figure 2.03* (left) summarises the three plans published by Carita (Carita, H. 1994, 20, 22, 26).
[51] "(...) a trama do espaço público não é utilizada, como na fase anterior e seguinte, como simples suporte de um sistema aberto e adaptativo a futuras mudanças da tipologia e gostos da edificação – mas como um imenso objecto unificado." (Portas, N. 2005, 53)
[52] (Portas, N. 2005, 47)
[53] (Oliveira, E.F. 1882-1911, vol. XIV, 354-357, 436-446, 496-500, 519; vol. XV, 316) *apud* (Madureira, N.L. 1992, 16-17). See also (Pinto, S.M.G. 2016, 162-163).

2.2.2 Cultural continuities in pre-and post-earthquake Lisbon

> "The city, however, does not tell its past, but contains it like the lines of a hand, written in the corners of the streets, the gratings of the windows, the banisters of the steps, the antennae of the lightning rods, the poles of the flags, every segment marked in turn with scratches, indentations, scrolls."[54]

> "[T]he city can withstand its reconstruction. In crucial moments in the culture of urban planning, Lisbon affirms its own memory of itself."[55]

In the aftermath of the massive catastrophe of 1 November 1755 (All Saints' Day) – an earthquake (whose magnitude was estimated between 8.5 and 9.0 M_w), a tsunami, and a fire – the historical core of Lisbon was reconstructed *in situ* from scratch.[56] The rebuilt downtown area (*Baixa Pombalina*) of 23.5 hectares consists of 62 blocks and 430 multi-storey buildings,[57] commonly called *prédios de rendimento pombalino*,[58] which constitute a specific building type in Lisbon.[59]

The new urban layout in *Baixa Pombalina* was based on a regular grid plan and was characterised by blocks arranged along the north-south direction in the northern area and orthogonally arranged in the southern area. Along the north-south direction, this nucleus was organised within the perimeter of two main former squares, porticoed and U-shaped *Terreiro do Paço* plaza and *Rossio* square (identified with '87' and '57' respectively in *Figure 2.04*). Given the fact that the area was partially reclaimed from the river, *Terreiro do Paço* – also christened *Praça do Comércio* – was larger than the former square. It was overlooked by the government bureaus, departments, and other port-related organisations. *Rossio*, also regularized in length, connected the northern area.

The main policy-making decisions owed to the Cartesian thought of Manuel da Maia, the elderly royal chief-engineer of Portugal. In fact, Manuel da Maia was appointed by Sebastião José de Carvalho e Melo, Secretary of State for Foreign Affairs and War, to set up a planning proposal for downtown Lisbon. Manuel da Maia duly defined five solutions in his *Dissertação sobre a renovação da Cidade de Lisboa* (*Dissertation on the renewal of the city of Lisbon*), from which the fourth was selected: reconstruction *ex novo* in the same place.[60] Six options based on this principle were then presented in 1756, from which the map of Eugénio dos Santos was

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[54] "Ma la città non dice il suo passato, lo contiene come le linee di una mano, scritto negli spigoli delle vie, nelle griglie delle finestre, negli scorrimano delle scale, nelle antenne dei parafulmini, nelle aste delle bandiere, ogni segmento rigato a sua volta di graffi, segnature, intagli, svirgole."(Calvino, I. 1996, 10-11)

[55] Maria Calado points out: "[A] cidade pode resistir nas suas reconstruções. Em momentos fortes da cultura urbanística, Lisboa afirma-se como memória dela própria." (AA.VV. 2010, 71)

[56] (Sousa, P.F.L 1909) (Sousa, P.F.L 1928)

[57] (Santos, M.H.R. 2014, 11)

[58] Now part of the Portuguese vocabulary, it was probably introduced in the last 25 years of the 19th century and means "intended to be rented" (CML 2004, 97).

[59] The traditional classification of Lisbon building stock executed before the obligation to provide a seismic analysis (1958), is divided into the following macro-categories: *Pré-Pombalino* (prior to 1755), *Pombalino* (1755-1880), *Gaioleiros* (1880-1940), and *de Placa* (1940-1960) (Appleton, J. 2008, 395-437). See *Figure 2.10*.

[60] *Dissertação* is divided in three parts, on 4 December 1755, 16 February 1755, and 31 March 1756. The last part was sent to the duke Lafões on 19 Abril 1756 (França, J. A. 1987, 77-93).

selected and executed.

A comprehensive literature covers different aspects of this district and other coeval rebuilding across the city as well as throughout the vast Portuguese Empire, e.g. villages of the Algarve[61] and colonial coastal areas (e.g. São Luís de Maranhão), including other unrealized plans.[62]

Architectural language and typological variations of the buildings in *Baixa*, including the pace of the works and other historical data, are thoroughly examined by many keen scholars, following the pioneering research carried out by França and Rossa.[63] In particular, Santos and Mascarenhas provide insight into the construction solutions of these buildings, deduced by on-site analysis and archival research (e.g. builders' contracts) and extensively described in their doctoral dissertations.[64]

Backed by this considerable knowledge, Lisbon City Council has also collected considerable data on the *status quo* of these buildings by detailed on-site surveys, probably with a view to nominating it for UNESCO World Heritage listing.[65] A dossier was submitted on 12 July 2004 but the process has not been concluded.[66] Scholarly interest in rehabilitation works for *Pombalino* heritage has been gradually increasing for the last decade, fostering awareness of the importance of safeguarding the built heritage and consensual concern around the current building practice, which is heavily subjected to the real estate market.

Reading the contours of rebuilt downtown Lisbon chiefly requires understanding the reasons why an *in situ* reconstruction was preferred over relocation to a nearby less seismic-prone area such as Bélem. In fact, the other site planning solution, moving the centre of Lisbon to the western area (the fifth hypothesis described in Maia's dissertation), was reasonable for the less-vulnerable soil[67], the wonderful waterfront view, and the feasibility of occupying this unbuilt site. However, a dramatic drop in the economic value of the former properties would have constituted a real deterrent to rebuilding the core of the city *ex-situ*. The importance attributed to the commercial value of the ancient site – strengthened before the earthquake by the construction of the aforementioned *Royal Palace* by Manuel I in 1498 – together with collective attachment to the place prevailed over the option to rebuild the city in Belém. Santos also suggests that the selection of the ancient site for the Enlightenment city would have been strongly influenced by the opportunity to reuse the piles of rubble (to lay the foundations for the rebuilt masses of houses) in order to reduce the transport costs for disposal of the wreckage, although it would have involved an increase in rebuilding time.[68]

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[61] A regular urban grid and anti-seismic construction techniques can be also found in Porto (1757), Vila Real de Santo António (1776), Porto Covo (1794), Manique de Intendente (1791-1800).

[62] The plan for the western side of central Lisbon – as defined in 9 April 1756 – would have covered an area of about 190 ha, marked by a oval or polygonal plazas and a series of star-like or orthogonal arteries, (França, J. A. 1989, 149).

[63] (França, J. A. 1987) (Rossa, W. 1998) (Rossa, W. 2002) (Rossa, W. 2015)

[64] Santos analyses ninety-three cases made with *Pombalino* system, of which fifteen were with their interiors under demolition, through on-site survey and archival documents (e.g. municipal dossiers, *post mortem* inventories) (Santos, V.L. 1994, II.4.1.9). In the same period, Mascarenhas formulates a hypothesis of a diachronic evolution of the *Pombalino* type via typological and construction analysis by examining nineteen buildings in demolition between 1986 and 1996 (Mascarenhas, J. 1996) (Mascarenhas, J. 2004, 78). For more extensive bibliographical references, see those included in (DGEMN 2004).

[65] When Lisbon Municipality carried out the submission of the *Baixa Pombalina* to the Tentative List of UNESCO's World Heritage, relevant antecedents did not exist in Portuguese law except in the case of fortified settlements, e.g. Marvão (1948) and Óbidos (1910) (Santos, M.H.R. 2000, 21, 177).

[66] (Silva, R.H. 1997)

[67] i.e. alluvial soft soils and Miocene fine sands (see *Chapter 5*, *Figure 5.07*).

[68] (Santos, V.L. 1994, II.4.1.15-17)



Figure 2.04 – Lisbon map: medieval tissue overlapped by the map drawn by Eugénio dos Santos de Carvalho and Carlos Mardel (BNP, cc-1373-2-a); detail of *Baixa Pombalina* and *Bairro Alto* (bottom)

One of the priority topics to be considered in this research is the cultural continuities between the pre- and post-earthquake in Lisbon. These continuities cover a wide spectrum of aspects, ranging from physical factors (e.g. same location of the re-built area, maintenance of visual and connective relationship of former public space), economic realm (e.g. private initiatives for financial profit, distribution of commercial activities according to a hierarchical order of the streets), and construction system (e.g. foundation system[69] and timber frame walls). Cultural, physical, and technical legacies intersect with modern purposes.

[69] Analogously to the timber frame walls in the vernacular houses, their foundations also draw from an ancient construction tradition (Farinha, J.S.B. 1997, 43-48). These consist of a series of foundation piles – generally in *Pinus silvestris* – along a tidal estuary, placed to stabilize the soil and transmit loads to the ground. The technical

From a formal point of view, the post-seismic response – more ambitious than what was actually carried out[70] – embodied "the matrix of the straight line"[71] ensuring the same principles included in the previous *Alignment Law* (*Ley do alinhamento*); this legislative antecedent is recalled by Manuel da Maia in *Dissertação*. Barreiros specifies:

> *"*(…) the passage from the private initiative to the greater public control does not introduce any rupture in the traditional procedure of creating streets and in the allotment that continued to be guided between the demand for a maximum rationality, the constraints of pre-existences and the financial availability of the tenants, as regards the size of the lots. Also in this case, there were no impositions or normalizations other than relative, the same principle applying for architectural solutions, namely in terms of composition of the facades."[72]

Shifting the focus to the socio-economic sphere, the hierarchal system according to different types of guild remained unchanged in the new city. The main thoroughfares – *Rua Augusta* and *Rua Aurea* – that connected the squares of *Rossio* and *Terreiro do Paço* were marked by shops of wool and silk traders and shops of goldsmiths respectively. Beyond these main arteries, the distinction between the other streets of this area, still based on the types of commercial activity at street level, was clearly expressed by their toponomy. However, these distinctions blurred over time in the dense network of relationships and variety of rental fees.[73] When the typological process is analysed, it should be noted that the building typologies and habits were already changing to cope with the expanding population prior to the great earthquake. Multi-storey buildings for rent – intended as *avant la lettre* collective housings[74] – had been disseminated throughout the city from the 15th century onwards, also arising from the agglutination of different plots (e.g. *Escadinhas de São Crispim*).[75] Moita reports the comments of the priest Sande in 1584: "Among other houses in this street [*Rua Nova dos Ferros*], admirable buildings are executed with so many floors and so many tenants that they do not recognize each other, neither by name nor sight."[76]

Evidence of this newly modern context can also be perceived in some palaces that remained unscathed after 1755, such as the Ludovice Palace (1670-1752), dedicated to a residence of the architect Ludovice and to rented apartments. Ludovice Palace, with two other multi-storey buildings in Lisbon – Almada Palace (1759) and *Casa das Varandas* (restored in 1763) – is viewed in literature as antecedent of the *Pombalino* architectural

knowledge of the engineers coordinated by Manuel Maia arose from broad experience with hydraulic structures built under the reigns of Pedro II, João V, and José I (Santos, V.L. 1994, 4.1.13).

[70] (Madureira, N.L. 1992, 20)

[71] (André, P. 2015)

[72] "(...) a passagem da iniciativa privada para o maior controlo público nenhuma ruptura introduziu no procedimento tradicional de abertura de ruas e no loteamento que continuaram a orientar-se entre a procura da máxima racionalidade, os condicionamentos das pré-existências e a disponibilidade financeira dos foreiros, em relação â dimensão dos lotes. Também neste caso, não houve imposições ou normalização senão relativas, o mesmo se verificando quanto às soluções arquitectónicas, nomeadamente em termos de composição das fachadas." (Silva, R.H. 1997, 49-50).

[73] (Madureira, N.L. 1992, 35-50)

[74] (Barreiros, M.H. 2009, 20)

[75] (Santos, N.B.; Cunha, R.M.; Alves, R.R.; Rodeia, T.B. 1993)

[76] "Há nesta rua [*Rua Nova dos Ferros*], além d'outras casas, edifícios admiráveis, de tantos pavimentos e com tantos inquilinos, que não se conhecem uns aos outros, nem de cara nem de nome." (Moita, I. 1983, 19)

style.[77] Ludovice Palace in *São Pedro de Alcântara,* contiguous to *Bairro Alto*, exemplifies Serlio's principles and is enriched by Roman Baroque details such as the curvilinear pediments of the pair of openings (*janelas de sacada*) framed between two simple giant lesenes in the central segment of the facade. Ludovice's house clearly differs from the typical architectural scheme of national palaces in its cubic shape and the doubling of the window-doors, whereas the rectangular shape and single *janela de sacada* prevail in the national palace-archetype (*Figure 2.05*, left). A symmetric and regular alignment of windows and balconies across a multi-storey volume, which characterises Palace Ludovice, can also be found in Almada Palace, located in *Largo da Madalena*, the border between the old and the regular pattern of the city. In addition to its austere architectural scheme, the low importance attributed to the entrance space and stairway should be taken into account – according to França's thought – as influential factors in the nearby-rebuilt tissue. A few meters away, walking through the almost-orthogonal *Rua da Madalena*, the other relevant pre-earthquake palace is *Casa das Varandas* in *Rua do Bacalhoeiros.* Regardless of its different overlapping layers (i.e. execution in 1741, alterations in 1761 by Francisco Crespo, addition of upper floors and two window-dormers during the early 1800s), the main facade is marked by a symmetric, uniform, and balanced layout, characterised by a non-hierarchical order across the different floors and the dynamism of the balconies.



Figure 2.05 – Pre-earthquake palaces in Lisbon: (left) Ludovice Palace (photo by M. Novais, between 1940s and 1950s, PT/AMLSB/CMLSBAH/PCSP/004/MNV/000680); (right) Almada Palace (photo by Machado & Souza, 1901, PT/AMLSB/CMLSBAH/PCSP/003/FAN/002823)

[77] (França, J. A. 1987, 177-179, 209-210) (Silva, R.H. 1997, 76-77, 131-132)

2.2.3 Proto-anti-seismic devices and on-site observations of building damage

While safety, transit, and health problems were addressed in efforts over the centuries to organize Lisbon's streetscape and layout through both royal reforms and private initiatives, town planning and building praxis also had to repair extensive damage from frequent earthquakes, which occurred in 1344, 1356, 1531, 1551, and 1597.[78] The 1531 earthquake was particularly devastating, with fifteen thousand houses destroyed.[79] As testified by an anonymous writer to the Marquis of Tarifa, Fadrique Enríquez de Ribera (1616-1633), the timber overhangs in the crowed *Rua Nova* collapsed during the earthquake of 1531, as well as entire dwellings all over in the city, for example in *Rua dos Fornos*.[80]

Moreover, other European post-catastrophe reconstructions, such as in the aftermath of the 1666 fire in London and of the 1669 volcanic eruption and the earthquake in Sicily in 1693,[81] were followed with particular attention, influencing thought in the Portuguese Kingdom. As a matter of fact, Marquis de Pombal claims in the missive to cardinal João da Mota e Silva: "All the European nation grew, and are still growing today, through reciprocal imitation. Each watches carefully the actions of the others. In this manner, following the information of their ministers, all of them make their own use of inventions".[82]

Focusing on Portuguese building praxis, Lisbon's ordinary dwellings[83] embodied some proto-anti-seismic devices, whose key principles can be understood in light of advancing knowledge of mechanical behaviour in historic buildings:

- lowering the centre of gravity by concentrating the mass as close to the ground as possible (through vaulted spaces in masonry on the ground floor, and wooden skeletons for the upper floors; through regular walls in masonry blocks[84] on the ground floor);
- reinforcement of structural discontinuity (e.g. proper dimensioning of the openings and their reinforcement by relieving brick arches);
- interlocking of components (each sub-component of timber frame walls and walls to floors)
- configuration of the roof, with tympanum facing the street side (acting as a pseudo-strut in order to prevent the outward thrust of the roof).

Before proceeding with the analysis of the medieval timber-framed structures, it is worth examining the ordinary built heritage that existed prior to the 1755 earthquake in Lisbon. In literature, this heterogeneous building group is divided according to construction system, resulting in three main categories: those characterised by (i)

[78] These earthquakes were of medium and high intensity; in particular, the earthquakes of 1344 (Lisbon) and 1356 (offshore Cape São Vicente) were similar to the earthquakes of 1531 and 1755 in terms of magnitude, as reported in literature, e.g. by Dias (AA.VV. 2005, 123-142) and other scholars (Ferrão, C.; Bezzeghoud, M; Caldeira, B.; Borges, J. F. 2016). The image of the hub of the city, *Rua Nova* before the 1531 earthquake can be grasped in the small watercolour attributed to António de Holanda, from the Book of Hours of King Manuel I (Museu Nacional de Arte Antiga, Lisbon, inv.no.14/130 Ilum, f.130).
[79] (França, J. A. 1987, 19)
[80] (Osório, B. 1919) *apud* Dias in (AA.VV. 2005, 140)
[81] (Rossa, W. 2015, 383-387)
[82] (Barreto, J. (ed) 1986, 158) *apud* (Murteira, M.H. 2004, 20).
[83] These were commonly called *casas urbanas não apalaçadas*.
[84] This type of wall structure is identified as *parede em alvenaria de pedra aparelhada*.

high or (ii) low quality of the masonry; or (iii) with overhanging floors.[85] The majority of the buildings of the latter category are composed of mixed facade with timber framework above a ground floor in masonry.

Taller buildings (up to three floors), heavy buildings with large wall spans, and buildings with overhanging volumes were considered the most vulnerable in Lisbon under static and dynamic loads, and more attention should be paid for the conservation and rehabilitation of these buildings.[86]

We may take issue with this assumption, however. In general terms, the high structural soundness of a building does not necessarily entail its stability.[87] It is plausible to suppose that crack patterns and even collapses occurred in any building sections that were not constructed according to the basic rules,[88] either in unreinforced masonry or in masonry reinforced by timber components, or sections with a particular shape (e.g. slender bell towers). The fact of constructing in wood does not by itself guarantee excellent seismic behaviour, just as masonry construction does not inevitably suffer serious structural damage under seismic stress. Rather, it is necessary to analyse the construction type and the relationship between its different structural components. As seen in many countries (Italy, Greece, Turkey), earthquake damage is selective: it does not occur at random but strikes only the weakest building sections, and these do not strain their adjoining portions.

Recognising the importance of complying with basic construction rules, it remains true overall that the dwellings with facades of timber frame walls – even those composed of jutting volumes – behave considerably better than masonry construction. These latter are more vulnerable to seismic actions due to the low tensile strength of the stone or brick blocks and mortar.

The structural reliability of timber-framed buildings was understood in an embryonic form by the post-earthquake survivors, one of whom was Friar Manuel da Epifania. In fact, among the debris, he noted two strengths of the timber structures – their lightness and the interlocking of their components (defined as “cage”):

> "In the earthquake of the 1st of November, it was seen that the Temples and houses with vaults collapsed more quickly; the houses made of strong walls, that is, of stone, and of lime fell down, destroying belongings and taking lives. On the contrary, the houses made of wall to the first floor, and made of *frontal* [i.e. timber frame wall] above that, will withstand much more. In any street in Lisbon where the fire did not pass, there is visible evidence of this fact; we walk through some of these streets, such as the street of Santo Andre, Paço do Bom-Formoso, Rua dos Anjos & c., and we see houses of [stone] walls up to the top ruined; and near to these many houses of *frontal* almost without any sign of having undergone the violence of such a strong attack. This is the experience; let us seek now the reason. Firstly, a wall of stone and lime has more stone that inclines it to the ground, compared to a *frontal*: secondly, the stone with lime does not provide such a strong cage compared to the beams, or pieces of the *frontal*, which are

[85] (Pinho, F.F.S 2000, 152)
[86] (Cabrita, A.R.; Aguiar, J.; Appleton, J. 1992, 56) (Farinha, J.S.B. 1997)
[87] (Giuliani, C.F. 2011, 27-28)
[88] The term *regola d’arte* (a workmanlike manner) is employed for the first time by Giuffrè as regards the traditional *ars construendi*, which involved the ability of the builders to execute the walls in almost isodomic fashion, taking two parameters into account: the stonework arrangement along the horizontal layer and the interlocking of the different leaves of the wall (Giuffrè, A. 1993).

interlocked one to the other by iron bars (...)".[89]

Depending on the shape of the facades of the vernacular constructions in Portugal built before the 1755 earthquake, we can also classify them in: (i) *casas de andares em ressalto* (overhanging houses) that are very common in the North, e.g. Porto, Lamego, Guimarães, Vila Real, and Chaves; and (ii) *casas com as águas em bico* (triangular facade)[90] that are more common in the southern areas, namely in Lisbon, Setubal and in Alcácer do Sal.[91]

However, even assuming the existence of a correlation between the distributions of the most common techniques and the lithological types in Portugal, a geographical subdivision is clearly reductive. In fact, this can be seen in Lisbon, the westernmost capital city overlooking the Atlantic Ocean and thus point of convergence of commercial trade and melting pot of different cultures.[92] Here, different construction systems merged in few building types[93] (*Figure 2.06*). The mixed construction system itself, which combines the masonry strength and the lightness of the timber, is likely to testify this multiple influence.



Figure 2.06 – Dwellings in Lisbon (16th century) with overhanging volumes and triangular facades: (left) in *Rua do Benformoso* no. 115 (demolished); (right) in *Rua dos Cegos* nos. 20-22 (Passos, J.M. 1997)

Oliveira and Galhano distinguish the ordinary buildings according to the external wall type, i.e. a group

[89] From *Novas e curiosas reflexões sobre os terramotos e uma oração trágica de Lisboa* (1756): "No terremoto do primeiro de Novembro, vio-se que os Templos, e casas de abobedas mais depressa se precipitáraõ; as casas feitas de paredes fortes, isto he, de pedra, e del cal vieraõ abaixo, destruiraõ os bens, e tiráraõ as vidas. Pelo contrario, as casas feitas de parede até o primeiro andar, e dahi para cima de frontal, resisteraõ muito mais. Em qualquer rua de Lisboa adonde naõ chegou o incendio se vê huma sensivel prova disto; passemos por qualquer destas ruas como saõ a calçada de Santo André, Paço do Bom-Formoso, rua dos Anjos & c., e veremos as casa de parede até cima arruinadas; e junto dellas muitas casas de frontal quasi sem sinal que padeceraõ a violencia de hum taõ forte ataque. Este he a experiencia; busquemos agoraa razaõ. Primeiramente, huma parede de pedra e cal tem mais pezo que a inclina para terra, do que hum frontal: em segundo lugar, a pedra com a cal naõ tem entre si huma prizaõ taõ forte, como tem as traves, ou barrotes do frontal, que estaõ prezos huns a outros com ferros (...)". (AA.VV. 2000, 111-112)

[90] i.e. building with the roof ridge perpendicular to the plane of the facade (*telhado de tesoura*, roof scissor-like shaped).

[91] (Pinho, F.F.S 2000) (Oliveira, E.V.; Galhano, F. 2003, 280)

[92] (Santos, N.B.; Cunha, R.M.; Alves, R.R.; Rodeia, T.B. 1993) (Fernandes, J.M. 2000, 127)

[93] "This is a typical model of the north of the Peninsula, which is also found in other parts of Central Europe and that when descends to Lisbon gains a specific own expression in contact with a Mediterranean tradition" ("Trata-se de um modelo típico do norte da Península, que se encontra também noutras partes da Europa Central e que descendo a Lisboa, ganha uma expressão própria ao contacto com uma tradição mediterrânea" (Pereira, N.T.; Buarque, I. 1995, 22).

with all external volume in masonry blocks, and a group of mixed facade,[94] i.e. made of timber skeleton[95] – overhanging or flat facade (*Figure 2.07*) – above the ground floor in stone masonry. These researchers suggest that the houses made with external timber frame walls in Portugal are very humble and are likely to be older than the stone structures – these latter more common at the beginning of the 17th century.[96] Similarly to what happened in the Vesuvian houses during the Roman epoch, the presence of external timber frame walls arises from the need for extra upper area.[97] As with many dwellings in Herculaneum, these projecting structures were very common due to the tendency to absorb outdoor space into the household: a sort of privatization of public space.

Three-storied houses abound in Lisbon and these would have been higher in the slope areas, reaching four or five floors.[98] The configuration of these houses has gradually been changed from more asymmetrical and unbalanced facades to regular shapes with regular disposition of the openings.

While many vernacular timber-framed structures provide evidence of the antiquity and autochthony of this technique, dating the timber frame walls in Lisbon's buildings is difficult to do with certainty. Metallic devices (so-called *ferrolhos*) nailed or screwed to the floor, were introduced to repair earthquake damage (failure arising from the separation of orthogonal walls) and to reinforce the connection between the floor structure and the external facades. Late-medieval examples of this wall type were replaced post-1755 by other walls, composed of the same system and similar materials, but with more regularity and accuracy. One case study is discussed by Appleton: an irregular interior frame wall in a building plot overlooking *Largo do Chafariz de Dentro* contrasts with a more regular external wall, which likely dates post-1755.[99] In the timber frame walls, the absence of bracing frames and the high irregularity of the skeleton and infill, as well as the irregularity of the spacing and cross-section of the wooden joists are crucial for dating the timber-framed construction (or its portions) (*Figures 2.08*, *2.09*).

[94] (Oliveira, E.V.; Galhano, F. 2003, 280)
[95] In general one of the two main elevations is overhanging, see the house in *Beco das Flores*, Lisbon (*Appendix B.1.2.4*) and in *Beco do Azinhal* (Santos, N.B.; Cunha, R.M.; Alves, R.R.; Rodeia, T.B. 1993, 63-70).
[96] (Oliveira, E.V.; Galhano, F. 2003, 280-281)
[97] *Chapter 1*, *section 1.3.1*
[98] (Santos, N.B.; Cunha, R.M.; Alves, R.R.; Rodeia, T.B. 1993, 16)
[99] (Appleton, J. 2008, 399) (Appleton, J. 2016, 25)

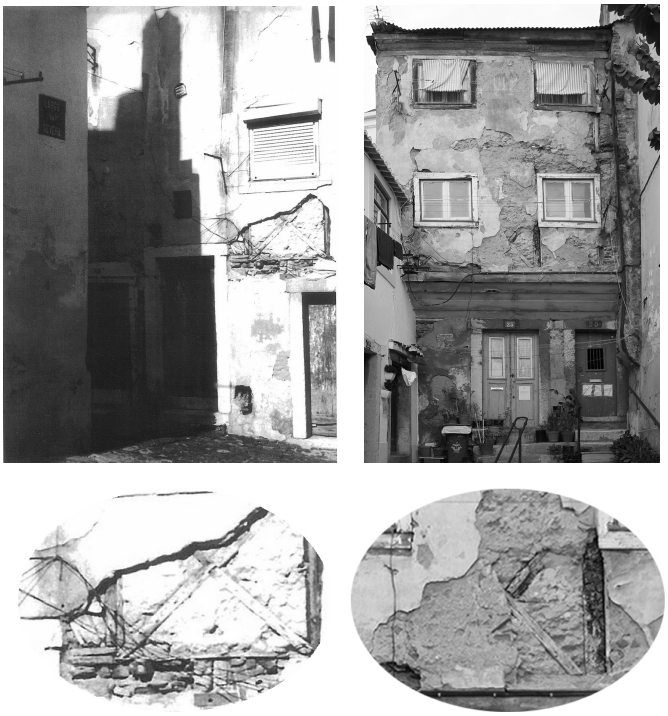


Figure 2.07 –Timber frame walls in pre-1755 dwellings in Lisbon: (left) flat facade in *Largo Severa* (Monteiro, N. 2006); (right) overhanging facade in *Beco das Flores* nos. 23-25 (2017)



Figure 2.08 – Timber frame walls in Lisbon's medieval dwellings: a) coexistence of pre- *Pombalino* and *Pombalino* walls in the same building; b) *Pombalino* staircase (Appleton, J. 2003, 401-402)



Figure 2.09 – Timber frame walls and *tabiques* in the 16th century building in *Rua das Farinhas*, Lisbon (© S.Stellacci)

2.3 Insight into Lisbon's overhanging dwellings (*casas de andares em ressalto*)

The humble timber-framed dwellings in old Lisbon have acquired symbolic value in the centuries following their construction. However, despite the historical and structural importance of these dwellings for guiding post-1755 building practice, there is still a lack of research into this building type and into the medieval houses in Lisbon in general. The still-standing timber-framed houses are implanted along medieval narrow and winding streets, especially in the traditional parishes of *Alfama*, *Mouraria*, and *Castelo* that form a dense urban tissue around the steep slope of S. Jorge Castle (*Figure 2.10*, area with pre-*Pombalino* buildings underlined in pink hatch).

This research shall be focused on those dwellings listed in the *Municipal Inventory of Built Heritage* included in the *Proposal of Detailed Zoning Plan of Urban Rehabilitation of Colina do Castelo*, and it shall be carried out by integrating archival data, on-site survey, and unpublished documents.[100]

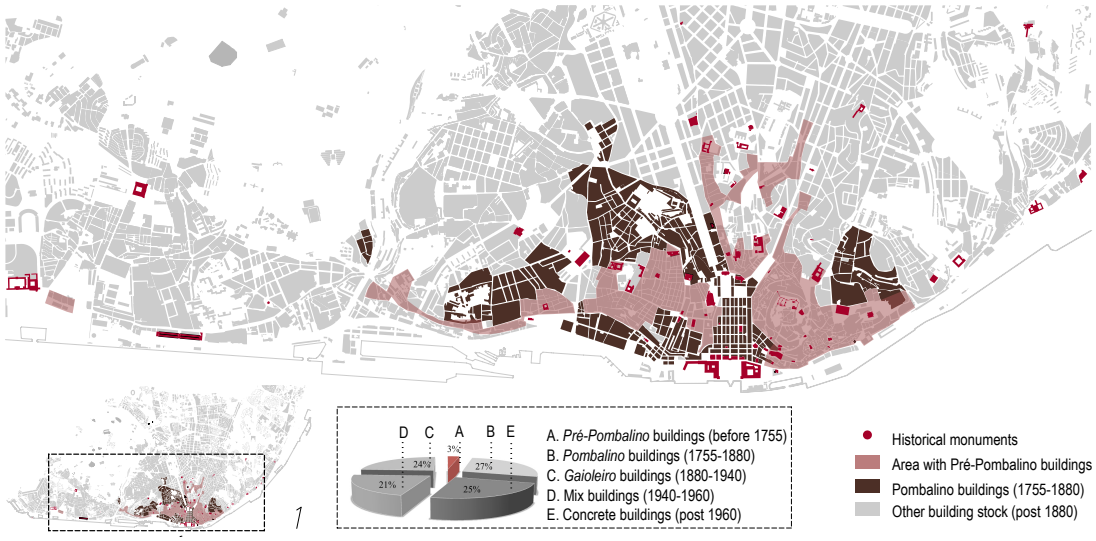


Figure 2.10 – Lisbon's building stock, data from (Sequeira, A.M. 1999) (© S. Stellacci)

2.3.1 Architectural and material characterisation of Lisbon's overhanging dwellings

The overhanging dwellings generally occupy long and narrow (*gothic*) plots. The plot is typically organized with a single dwelling per floor and shops on the ground floor, connected by a steep straight flight stair (i.e. angle of the inclination of the scale is more than 45 degrees), so-called *escada em tiro*, with 0.60 m width; each step supported by a side wall in stone masonry. If the depth of the lot was too small, the vertical access bounded the perimeter of the house (L-shaped). The average inter-story is approximately of 2.20 m. The overhang depth and other specific features of these buildings are highly variable:

> "The houses amalgamate more in color than in volume. (…) Timber floors overhang above the other. Some overhang of the first floor or mezzanine to the ground floor, others from the second to the first floor (…)".[101]

[100] Dossiers collected in AML and listed in the *Appendix B.1.1* (CML 2010). See also the report from (Appleton, J. 1991) (Santos, N.B.; Cunha, R.M.; Alves, R.R.; Rodeia, T.B. 1993) (Pereira, N.T.; Buarque, I. 1995, 22-35).
[101] "As casas amalgamam-se mais na côr que no volume. (...) Sobrados ressaltam sobre os de baixo. Uns avançam as paredes do primeiro andar ou sobreloja para o rés-chão (...)" (Chaves, L. 1936, 19).

Even though they may be from late reconstruction, various opening layout can be noted depending on plan and the type of roof. The main facade has usually very small openings. In the case of corner buildings or setting on a trapezoidal or quadrangular plan, the row of the openings is arranged along the entire facade (*Beco de São Miguel* no. 17, *Beco das Flores* nos. 23-25, *Largo Achada* nos.1, 9, 9A), by contributing to a certain symmetric layout. Conversely, terraced buildings (*Rua Benformoso*[102] – still existing one of three original building units, *Largo do Chafariz de Dentro* nos. 32-33) have less openings, always in the small living room overlooking the alley. Tiny openings on the underside of the overhangs (i.e. below the projecting volume, as shown in *Figure 2.11*) are other peculiar elements, as can be still seen in *Beco de São Miguel* no. 17, *Largo da Achada* nos. 1, 9, 9A (*Figure 2.12*). Single or multiple overhangs can be found on one side or in two directions in the building corner (*casas em gaveto*), as the multi-storey dwelling in *Largo da Achada* no. 9/9A, demolished for its structural instability. In some few cases, the overhangs rest upon single or multiple columns, such as in the volume in the *Patio do Carrasco*,[103] as shown in photo of Eduardo Portugal (1900-1958) (*Figure 2.13*), and in *Rua de São Pedro* nos. 16-18. However, it is assumed that before 1755 the presence of columns was widely common, as shown by the 149 pinkish marble columns running up the whole *Rua Nova dos Mercadores* (*Figure 2.01*).[104]

Upper facades have a single or double overhang ranging from 0.20 m to 0.90 m with thinner walls (0.15-0.20 m of thickness), which combines the flexibility of wood and the compressive strength of stone blocks and bricks. Mortar made with lime and sand is generally used as filling material and provided the masonry a monolithic behavior even under earthquake action. Timber planks originally protect the overhanging jetties from atmospheric agents. Although *Castanea Sativa* is a commonly used, other wooden species are found as a consequences of a widely import of all types of products, and also due to the frequent replacement over the centuries. For example, wood was imported from Atlantic islands during the first phase of the Portuguese ultramarine expansion.[105] As evidence of this, the samples taken from floor beams in the building in *Rua da Guia* nos. 1/7 were *Pinus Pinaster Ait*., and are not thought to belong to the original construction period. In fact, the original round section beams supporting the timber floor were made of *Pinus sylvestris* and *Castanea Sativa*.[106] However, data regarding wood species remains incomplete until now.

[102] Building declared of *Public Interest* on 24 January 1983 with Decree Law no. 8/83, DR, I Série, no. 19.
[103] The toponymy of this patio arises from the probably residence of an executioner. Gameiro's engraving shows the surface of the volume marked by the timber X-bracing (Gameiro, A. R. 1993, 63).
[104] (Gshwend, A.J.; Lowe, K.J.P. 2015, 112-115)
[105] (Zurara, G.E. 1949, 104)
[106] (Appleton, J. 1991, 4-5). This case study is analysed in *Appendix B.1.2.3,* by including data from (CML 1993, 85).



Figure 2.11 – Openings protected by timber overhangs: (left) in *Rua do Benformoso* and detail (phtoto by J.A.L. Bárcia, 1900-1945, PT/AMLSB/CMLSBAH/PCSP/004/BAR/000832); (right) in *Beco da Achada* (photo by M. Novais, 1959, PT/AMLSB/CMLSBAH/PCSP/004/MNV/001090)

Unlike the external facades of the upper floors generally made of timber frames,[107] gable walls (in the whole height of the buildings)[108] and walls at ground floor are typically made of mixed stone and brick. These walls are very thick (approximately 0.60 to 0.70 m), made of irregular blocks of limestone and massive ceramic bricks (0.12 x 0.25 x 0.03 m), clay with lime as binder, and plastering lime mortars with clayish sand with an aggregate size of 0.15 - 4.80 mm.[109] Regular laid bricks are employed to fill gaps between masonry stone blocks. Ceramic bricks are used for safety arches above the openings, cornices, and in other architectural details.

To the rear, a small and open area (*logradouro*) is generally devoted for household activities and is fundamental for ventilation. No corridors and sanitary installations are included. Beside small round windows without stoneworks, the openings are protected by timber planks or *mucharabiés* (windows are introduced during Lisbon rebuilding works). Inherited from Islamic customs, these grilles protect residents from the sun and allow them to look the street without being seen, and these were later employed in Brazil.[110] In Lisbon, they are deemed as one of the most relevant cause of the difficulty in controlling the fires following the 1755 earthquake, and thus its use was publically forbidden in the building permit of 12 May 1759.

[107] Some overhangs entirely in masonry can be found at Lisbon, e.g. in *Calçada do Marquês de Tancos* no. 18.
[108] Trinidade enriches the analysis of this lot alleging the walls between two ownerships were normally constructed with more solid materials, providing a character of greater permanence to the allotment (Trindade, L. 2009, 179).
[109] (Pinho, F.F.S 2000)
[110] (Carita, H. 1994, 163) (Gshwend, A.J.; Lowe, K.J.P. 2015, 110-111, 119)



Figure 2.12 – Overhanging multi-storey building in *Largo da Achada*, Lisbon (photo by E. Portugal, before 1958, PT/AMLSB/POR/052752)



Figure 2.13 – Timber-framed volume supported by an elegant column, in *Pátio do Carrasco* (photo by E. Portugal, PT/AMLSB/POR/059233)

The interior area is subdivided by timber frame walls referred to as *frontais* (*Figure 2.14*, left). The definition of spatial concepts revolved around the dichotomy between public and private spheres (street/house); the first known use of the term *frontal* to define an external wall is in legislative documentation related to the renewal of *rua das Eiras* in Porto at the end of the 15th century.[111] It is important to stress that later, over the centuries, the term *frontal* has been associated in Portugal to the traditional timber framework even though it was mainly applied as an internal (or external) structure wall during the recovery of *Pré-pombalino* houses in the post-earthquake reconstruction and, in particular, in the 18th century *Pombalino* buildings.

Besides the *frontais*, the small compartments were also divided by the so-called *tabiques* timber walls, made with vertical timber boards or diagonally crossed (0.10 m in thickness) and covered by lime and clay mortar with a gypsum plaster finishing. Unlike other European examples, the traditional timber walls of the upper floors were always protected by plaster in a three-layer scheme, in order to regularize and protect the surface (three layers: *emboco, reboco, esboço*), and by a finishing layer (*barramento*), above which the painting was applied. Mineral and organic additives were often used to improve water resistance and adhesive properties.

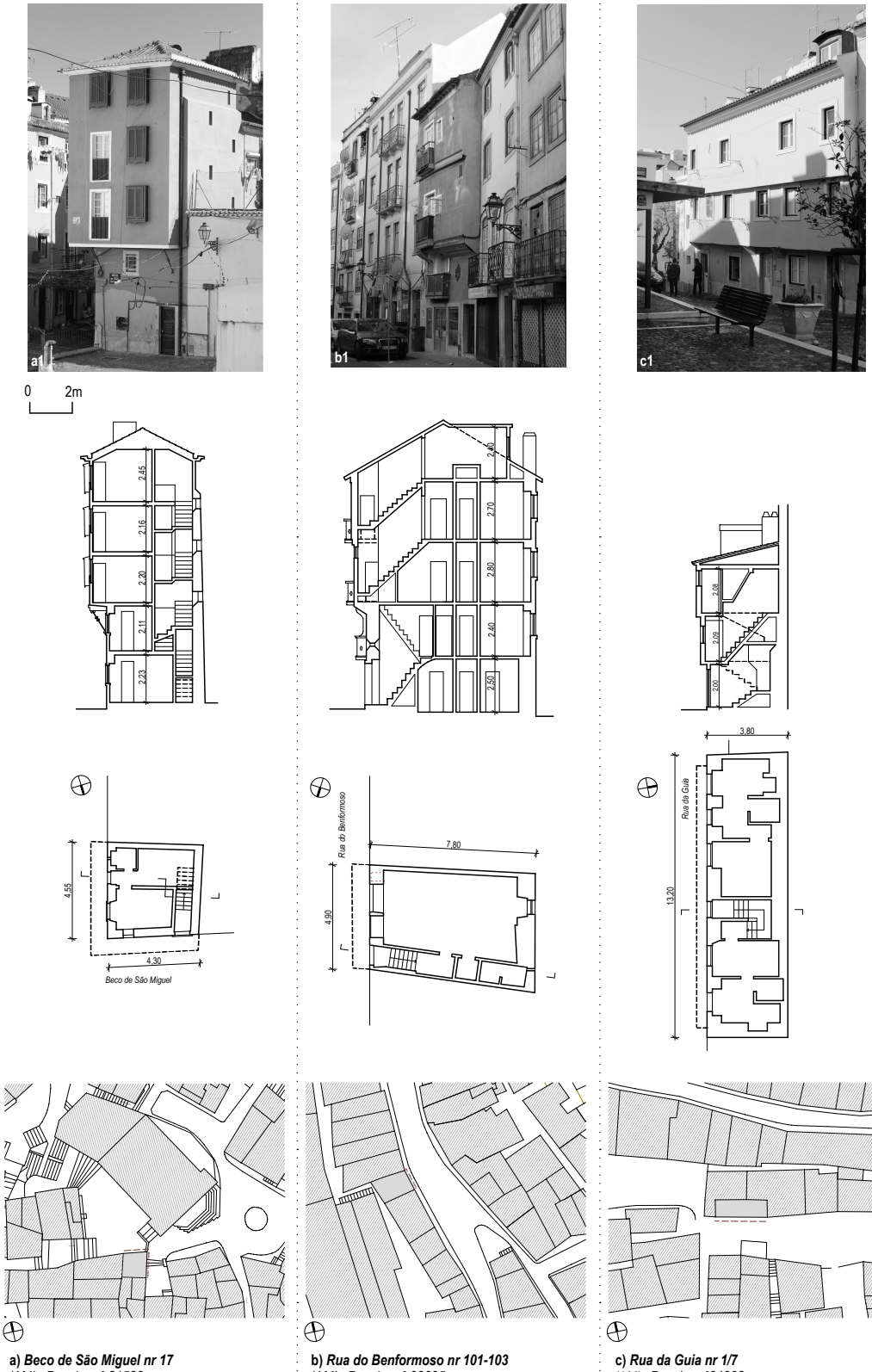
In both the internal and the external surfaces, mortar layers are made with a decreasing binder-to-aggregate ratio to promote a progressive deformability and increase porosity from the inner to the exterior layers. The surface layers were prepared with lime paste and fine stone particles. The final layer was ochre or pink, obtained from iron oxide and natural blue pigments, or with a base of white lime and additives made from tallow (vegetable or animal fat). These mortars exhibit high water solubility, low shrinkage, sizable adhesion to the substrate, low mechanical strength, adequate porosity, and good workability (*Figure 2.14*, right).



Figure 2.14 – (left) Connection between different surface walls: *frontal vs tabique* building in *Estrela* district (*Lapa*, Lisbon); (right) marks in the wooden skeleton, building in *Misericórdia* district (*Cais do Sodré*, Lisbon) (© S. Stellacci)

Figure 2.15 shows three selected case studies of Lisbon's overhanging dwellings, with different state of conservation and degree of authenticity. Additional information can be found in *Appendix B.1.2*.

[111] (Pinto, S.M.G. 2016, 158-159)



a) *Beco de São Miguel nr 17*
(AML, Dossier nº 21582,
Proc. 21582/1941)

BILATERAL OVERHANGS

b) *Rua do Benformoso nr 101-103*
(AML, Dossier nº 33695,
Proc. 2184/08/1985)

DOUBLE OVERHANGS ON ONE DIRECTION

c) *Rua da Guia nr 1/7*
(AML, Dossier nº34998,
Proc. 712/EDI/2004)

DOUBLE OVERHANGS ON ONE DIRECTION

CURRENT STATE

Figure 2.15 – Three overhanging dwellings in Lisbon: (a) in *Beco São Miguel* no. 17; (b) in *Rua do Benformoso* nos. 101-103; (c) in *Rua da Guia* nos.1/7 (© S. Stellacci)

2.3.2 Transition from traditional timber frame structures to the Pombalino system

The technical continuity between the construction praxis before and after the 1755 earthquake is not extensively discussed in literature, although some researchers mention the common technical background of the carpenters and builders consolidated in the shipyards and timber-framed houses through the centuries.[112]

The few buildings in Lisbon that survived the 1755 earthquake are noteworthy for their small number and for their symbolic value, as well as for the examples they provide of the construction processes that would evolve into more informed and effective solutions during the post-earthquake rebuilding.

Leaving aside the differences in their architectural composition and internal layout, a comparison between the mixed structures pre- and post-earthquake in Lisbon is drawn below. It is worth noting that some operational aspects nevertheless remained unchanged in the 18th century. In fact, in both medieval constructions (including the overhanging dwellings) and *Pombalino* constructions, the connection between the timber skeleton of the walls and the floors results in an integrated load-bearing system.

In general terms, the main difference between pre- and post-earthquake systems in Lisbon lies in a number of construction improvements to the regularity, modularity, and accuracy of details that, in turn, give the *Pombalino* system greater structural redundancy (hyperstaticity). In addition, despite the similar structure and materials, the external volumes differ for the absence of all types of jutted structures in *Pombalino* buildings (either decorative heavy features or balcony), in compliance with the law of 16 June 1758.

Table 2.01 – Overhanging dwellings *vs Pombalino* buildings

		Overhanging dwellings pre-1755	***Pombalino* buildings post-1755**
Built environment	urban layout	diachronic planning	synchronic planning
		low-income class of inhabitants	middle class inhabitants
		compact and irregular layout, narrow streets	regular layout, well-ranked streets
		main road axis parallel to the waterfront	main road axis orthogonal to the waterfront
Construction system	external walls	ground floor and gable walls in mixed stone and bricks; upper floors: overhanging facade in timber frame wall, the others in mixed stones and bricks	flat facade at every level: mixed masonry and nailed timber frame close to the internal face; systematic connection between internal skeleton and floor structure
		uneven and irregular connections	connections to joists through metal ties
	internal walls	three dimensional structure	three dimensional structure
		the vertical alignment of the posts is not guaranteed at every level	vertical alignment of the posts at every level
	1st floor structure	low and irregularly-spaced parallel joists bearing on perimeter walls; the joists are oriented perpendicular to the main elevation	vaulted stones, arches, or timber joists
	upper floors structure		low and regularly-spaced parallel joists bearing on perimeter walls; the joists are oriented perpendicular to the main elevation

Table 2.01 shows the comparison of the overhanging dwellings (pre-1755) and the *Pombalino* buildings (post-1755) in terms of built environment and construction system.

(i) *urban layout*: The location, configuration, and orientation of each building plot (including the overhanging dwellings) were defined by the diachronic development of the urban settlement. Similarly to other vernacular houses in the city, the overhanging dwellings were located along irregular morphological patterns. This type of building, whose function is commonly mixed (residential, craft shops), was typical of low-income areas.

[112] (Carita, H. 1994, 105) (Penn, R.; Wild, S.; Mascarenhas, J. 1996, 4) (Mascarenhas, J. 2004, 83)

Despite the satisfactory original seismic response – as tested by the 1755 earthquake – decay, neglect, or intrusive works have greatly compromised the original structural reliability of these dwellings. The uneven behaviour of the current buildings is also due to the subsoil and the different levels of their foundations (which are direct and continuous), as well as rehabilitation works done to single plots included in heterogeneous blocks, lacking integrated planning.

Conversely, *Baixa Pombalina* arose from enlightened absolutism, synchronically-planned for the emerging bourgeois class (mostly craftsmen, traders, and tenants). Working and domestic spaces are organized in a regular and homogeneous urban grid. Unlike the main medieval road, *Pombalino* main axis – *Rua Augusta* – and the main orientation of the building stock are orthogonal to the estuary basin (north-south axis), which corresponds to the main earthquake shocks. The ground soil of sedimentary layers was compacted by a type of foundation able to transmit the weight through wooden stakes, while employing wreckage from the collapsed structures made it possible to increase the overall street elevation.[113] *Pombalino* building stock was conceived to improve stability and achieve a block effect,[114] where the response of each plot would also depend on the other connected buildings of the block. However, many alterations over time have seriously compromised the original construction homogeneity and their interlocking systems.[115]

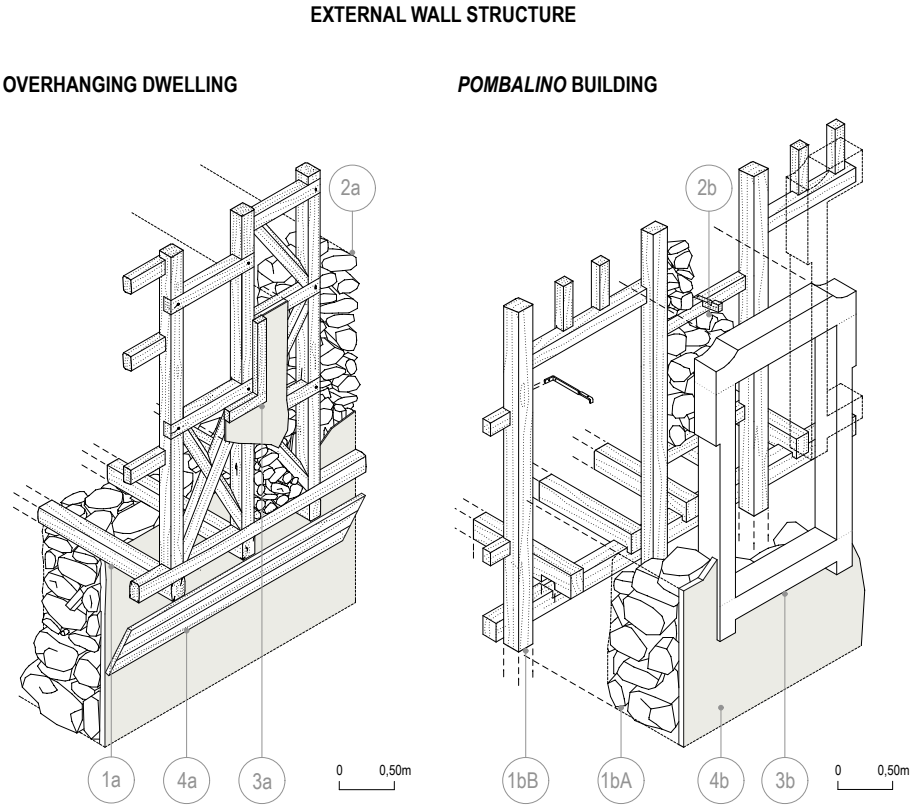
(ii) *load-bearing walls*: The bracing elements of the external overhang walls and internal partitions are highly irregular in the pre-1755 constructions. Vertical continuity of the posts within a wall over the height of the structure is not guaranteed; moreover, the lack of systematic connections between the overhanging walls, the interior structures, and the side-walls is a significant structural weakness.

For its part, *Pombalino* system is characterized by the execution of a grid of timber-framed walls as an internal and continuous framework, called *gaiola* (a polysemic term meaning cage).[116] The systematic use of Saint Andrew's crosses guarantees the bracing of the elements, a less fragile and more ductile behaviour, as observed in various experimental analysis carried out on such walls.[117]The regular bracing components and the use of timber-framed walls guarantees an increase in shear resistance.[118]

The external *Pombalino* walls have a more simplified structure than the internal wall of the same building (*Figure 2.16*). In fact, the external walls are made of mixed masonry and a nailed wooden timber frame close to the internal face. These walls present a few timber elements that are linked to the joists and the half-timbered walls by metal ties, which should prevent to some extent an early out-of-plane failure. Nevertheless, a peculiarity of this type of building is that, if there is an earthquake, the heavy exterior masonry walls may fall down but the

[113] (Mascarenhas, J. 2004, 42)
[114] (Coías, V.C. 2007)
[115] *Chapter 5*, *sections 5.1*, *5.2.1*
[116] *Gaiola* from latin *caveola*: "A kind of portable house, ordinarily made of cane or rods, with wire, and used to contain live birds "(...). Jail, prison. *Build.*: The space enclosed by the four walls of a house. Lumber that forms the skeleton of a building. (...) Building hurriedly built with second-rate materials, subject to collapse with rain or thunderstorms". Pt: "Espécie de casinha portátil, ordinariamente feita de cana ou verga, com fio de arame, e que serve para nela se encerram aves vives" (...). Cárcere, prisão. *Const.*: O espaço fechado pelas quatro paredes de uma casa. Madeiramento que forma o esqueleto de um edifício.(...) Edifício construído a pressa com materiais inferiores, sujeito a desmoronar-se com as chuvadas ou temporais" (Silva, A. 1953, 395-396).
[117] (Meireles, H.; Bento, R.; Cattari, S.; Lagomarsino, S. 2012) (Poletti, E. 2013) (Gonçalves, A.M.; Gomes-Ferreira, J.; Guerreiro, L.; Branco, F. 2014)
[118] (Poletti, E.; Vasconcelos, G. 2015)

timber frame should remain standing and thus the floors collapse is avoided.[119] If the connections between the external masonry piers and the internal skeleton are adequate, the out-of-plane collapse mechanism of the external facade may be minimized.[120] The concept of allowing a partial collapse if an earthquake occurs is also common to other cultures, e.g. in the timber-framed houses in Lefkas, the masonry walls on the ground floor could collapse, while a secondary structural system – consisting of timber posts – would support the upper timber-framed stories.[121]



1a. overhanging facade: a wooden timber laying on floor structure
2a. external rubble stone masonry wall
3a. timber door jamb (or plaster)
4a. wooden boards covering the overhang

1b. flat facade: a mixed masonry (A) and nailed wooden timber frame (B)
2b. rubble stone infill
3b. Lioz limestone door jamb
4b. no external timber structure

Figure 2.16 – Isometric view of the external walls: overhanging facade *vs Pombalino* façade (© S. Stellacci)

To sum up, the *Pombalino* internal structure systematised the former traditional timber technique by:

- a regular execution of Saint Andrew's crosses;
- the robustness and the regularity of its components;

[119] Regardless the almost unanimous explanation of this out-of-plane damage of the external facade in literature (Pinho, F.F.S 2000, 162-3) (Mascarenhas, J. 2004, 318), some doubts can be raised in multi-storey *Pombalino* buildings, whereas smaller mixed houses have behaved with this damage mechanism, as testified in the 1998 earthquake in Açores (Cardoso; R. 2002, 9).
[120] (Vasconcelos, G.; Lourenço, P.B.; Poletti, E. 2013)
[121] (Vintzileou, E.; Zagkotsis, A.; Repapis, C.; Zeris; C. 2007)

- a regular laying of the infill;[122]
- the accuracy of the connections (carving or nailing);
- a vertical alignment of the framework at every levels.

In addition, it is noted that the opening size is reduced in the medieval buildings to avoid the interruption of the timber framework in the overhanging facade.[123] This constraint is overcome in *Pombalino* buildings by executing a masonry facade, in order to assure the stability of openings without considerably compromising the overall mechanical resistance (*Figure 2.16*, right).

(iii, a) *first level floor system*: The traditional overhanging dwellings have wooden floors (*sobrados*) bearing on thick limestone walls at every level, and – in most cases – leaning against retaining stone walls (*empenas*). Brick vaults are very rare in this type of ordinary building, whereas in coeval palaces they can be found not only on the ground floor but also on the upper floors.[124]

In *Pombalino* buildings, three different types of the first level floor can be found: vaults, arches, or timber joists bearing on massive pillars or walls. These solutions were employed against the propagation of fire[125] and to create spaces large enough to accommodate commercial activity. They depend on the importance of the street and the type of activities to be practiced, as stated in the 1758 legislative provision.

The vaults of *Pombalino* buildings were not a novelty, since they were present in the constructions of the late 17th century, e.g. in the noble houses in Lisbon and in the nearby areas.[126] Vaults and arches provide more rigidity in height:[127] in addition to the external walls, vaults are supported by limestone pillars connected to stone vaulted ceilings (barrel or groin vaults, made of soldier course bricks) or arches, executed parallel to the main facade. The vertical posts of the timber frame walls of the first floor are driven into the upper side of the vault.[128]

A detailed field analysis by the researchers Duarte and Gouveia[129] shows the coexistence of these three construction systems along the main road axes (*Rua Augusta*, *Rua dos Sapateiros*, and *Rua dos Correeiros*). Although this analysis does not cover the whole area, interesting aspects are discussed. In the first phase of Lisbon's reconstruction (1762-1779), the use of vaults supported by thick walls prevails, as well as small compartments typically executed at the rear of the building. As an alternative system, wooden joists are also very common in the first phase of the works, probably following "the way to execute timber structure in the houses and patio" illustrated in the cross section of two buildings (June 1758-June 1759)[130] (*Figure 2.17)*. During the second phase of the works (1790-1810), skillful use of materials and techniques allowed the large-scale execution of

[122] However, different types of infill are found even in the same building (see *Chapter 4, section 4.3.3.1*).
[123] (Santos, N.B.; Cunha, R.M.; Alves, R.R.; Rodeia, T.B. 1993) (Oliveira, E.V.; Galhano, F. 2003)
[124] (Santos, N.B.; Cunha, R.M.; Alves, R.R.; Rodeia, T.B. 1993, 34)
[125](Melo, S. J. C. 1830, 8)
[126] Vaulted stone can be found in Lisbon's unscathed palaces of 16h-17th centuries, e.g. *Palácio de Marquês de Tancos* in *Rua da Costa do Castelo* nos. 23-27 (Appleton, J. 2016, 25).
[127] Since it requires a skilled labour and even more resistant than arches groin vaults were less frequent; thereby they were executed when the activities might be taken facilitate fire propagation (e.g. haystacks, turners).
[128] (Mascarenhas, J. 2004, 80-82)
[129] (Duarte, A. R. L. 2011) (Gouveia, J.P.J. 2014)
[130] From the drawing entitled *Corte transversal assinalando o sistema de condução dos esgotos* (AHOP, D 15-1 A.L.): "(...) a forma de madeyrar as casas e os patios". The real effectiveness of the sewage system of this epoch is questioned by Santos, based on evidence of the use of alternative systems employed (disposal out the window into the streets, execution of pits for the deposit in the building blocks, containers whose contents were thrown in the river), employed until the improvement of the sewerage in this district in the mid-19th century (Santos, V.L. 1994, II.4.1.68-70).

brickwork arches to achieve large spans. Gouveia suggests that the last building plots to be built were reserved for wealthier buyers.[131]As shown above, the construction systems for covering the ground floor (as well as the typological layout of the entire building) progressively depart from medieval models.

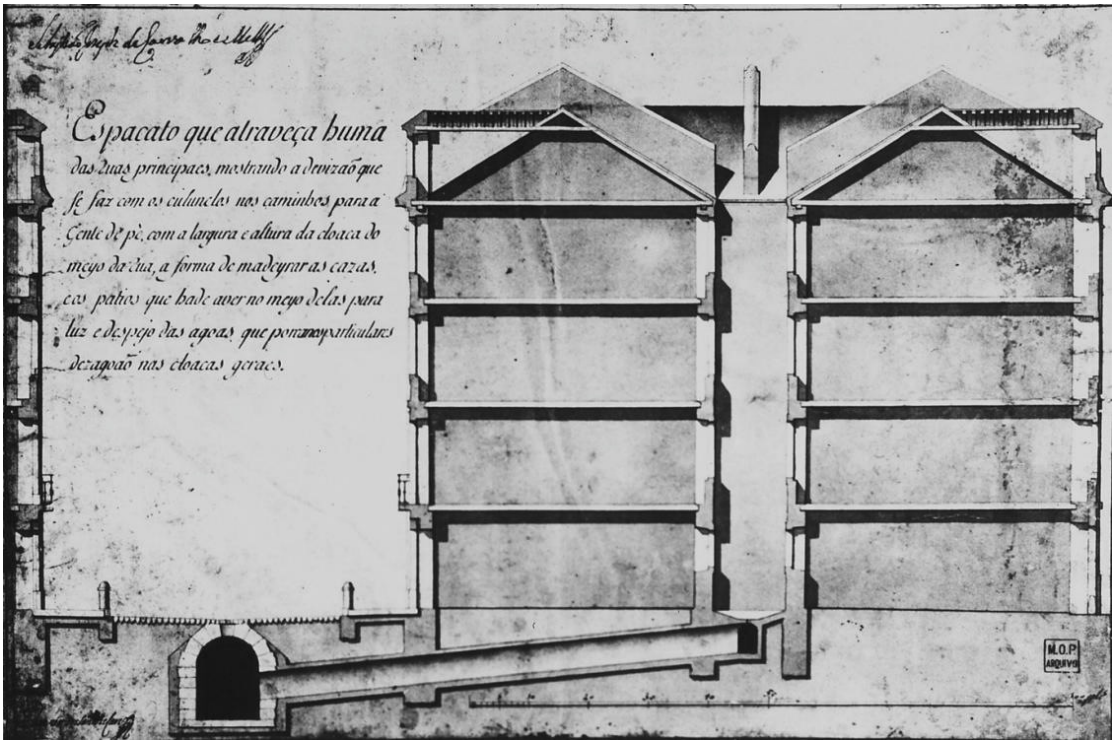


Figure 2.17 – Cross section of *Pombalino* buildings with the indication of the sewerage (AHOP, D 15-1 A.L.)

[131] (Gouveia, J.P.J. 2014, 73)

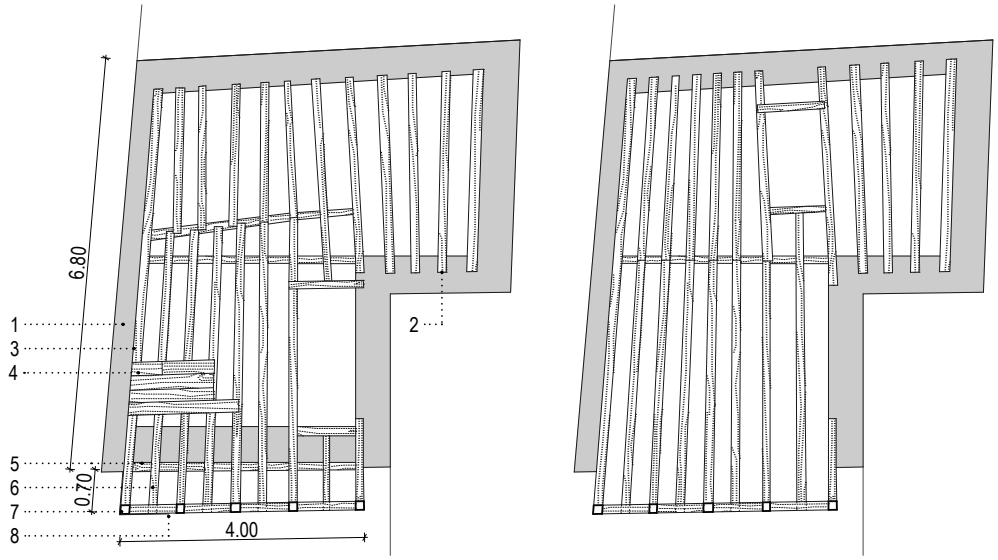


Figure 2.18 – Floor structure of a pre-1755 overhanging house, in *Beco das Flores* nos. 23-25 (Lisbon)[132]

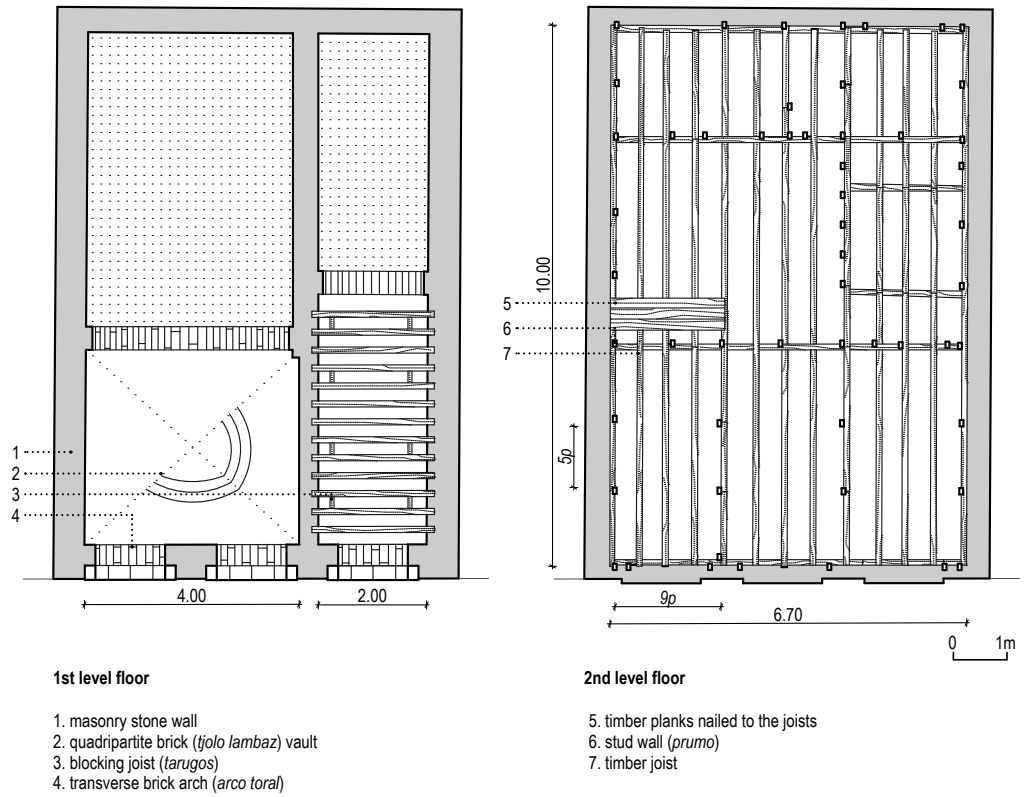


Figure 2.19 – *Pombalino* building in *Rua Áurea* no. 60 Lisbon, 1st floor plan, adapted by archival documents (dot pattern = no data available (© S. Stellacci);[133] 2nd floor plan, adapted from (Penn, R.; Wild, S.; Mascarenhas, J. 1996, 10)

[132] Drawings reprocessed from Santos et al. (Santos, N.B.; Cunha, R.M.; Alves, R.R.; Rodeia, T.B. 1993, 51) and by Appleton (Appleton, J. 2003, 148)(© S. Stellacci). See *Appendix B.1.2.4*.

(iii, b) *floor system of upper floors*: Executed to lock the overall construction, the floor structures of overhanging and *Pombalino* buildings consist of closely-spaced parallel joists bearing on perimeter walls and placed perpendicular to the main facade, even when it would have been cheaper to put shorter joists parallel to the main facade. When the use of a single piece – with length equal to the width of the span to be covered – is prevented due to the great depth of the plot, a beam is placed orthogonally as a middle support above the *frontal* on which the joists were nailed (*Figure 2.18*). In the medieval buildings, the floor joists, on which the internal and the overhanging frame walls rest, are suitably fixed together in the transverse direction with blocking joists.

The joists are sheathed with timber boards on top. Wooden planks, ranging from 15 to 25 cm in width and thicknesses of 1 or 2 cm, form the so-called *saia e camisa* or *forro encabeirado* underneath, which is nailed to the lower surfaces of the joists, forming the ceiling.[134]In the vernacular constructions, the overhanging volume rests on a continuous beam jutting out from the external wall. In some cases, the overhanging facade is held up by stone blocks in order to increase the dimension and quality of support (e.g. in *Rua da Regueira* no. 37, Lisbon).

Conversely, cantilevered areas are definitely not allowed in the *Pombalino* system; the floor beams rest on a continuous beam (*frechal*) within the wall thus allowing direct distribution of the loads (*Figure 2.19*). Two beams on the top of the walls are commonly reinforced by small *tarugos* in the transverse direction to prevent lateral displacements.

When the *Pombalino* system is compared to the medieval floor structures, it shows:

- higher material qualities of wooden components;
- regular cross sections of wooden components and regular spacing of joists;
- continuous beams for the entire depth of the building;
- use of long plates of ironwork (*ferrolhos*) fixed on the joint area of the top surface or side of the beams to masonry walls to improve the floor´s stiffness and the out-of-plane stability of the vertical frames;
- connection between the orthogonal walls through the vertical posts common to two walls;
- connection between horizontal and vertical structures (e.g. nailing of the joists to timber members embedded in the masonry walls).

In both cases, the carpentry joints used are half-lap, mortise-and-tenon, dovetail joints, and other notched connections. These types of joints have shown a good seismic behaviour with a great dissipative capacity. As a matter of fact, pull-out and in-plane cyclic tests performed on half-lap joints, similar to those used for traditional timber-framed walls, have shown the good deformational capacity of the joint, together with the great dissipative capacity that is then exploited by the walls.[135] The seismic-performance of carpentry joints is also confirmed for other types of joints. Various studies related to many timber roof structures are available on bird's mouth connections, pointing out the good moment-resisting capacity of the connections.[136] For seismic-resistant purposes, strengthening performed with metal devices is essential to increase the joint's ductility and viscous

[133] AML, PO 27452, vol.2, 4120/OB/1989, folha 12
[134] The first type is made of parallel timber planks alternating on ledges – *de camisa* – and in recesses – de *saia*. The second type uses a series of parallel pieces cut in half in the transverse direction and framed by other pieces.
[135] (Poletti, E. 2013)
[136] (Branco, J.; Piazza, M.; Cruz, P. J. 2011)

damping. In addition, in the *Pombalino* buildings, the floor is reinforced at the corner by timber joists placed 45º degrees in order to connect two orthogonal walls.[137]

Pombalino buildings and naval constructions have in common a symmetrical structure on transversal direction and the type of carpentry joints. Farinha[138] mentions these analogies between *Pombalino* buildings and naval constructions, by emphasizing the central role of the *Casa do Risco das Obras Públicas* (Lisbon Public Works Draughting Office), previously called *Sala do Risco do Arsenal da Marinha* (Navy Arsenal Draughting Office). Geometric traces of the ships were executed in full scale in the enormous space in the building, close to the Royal Palace and the arsenal. Technical knowledge about wooden species, types of treatments, and connections, passed thus down through generations. The rebuilding process was facilitated by the abilities of local workers linked to shipbuilding and thanks to pre-fabrication experience, as witnessed during the colonial expansion period. The training of the Portuguese military engineers was done in the *Aulas de Fortificação e Engenheira Militar* that took place in different seats of the military government, including in Lisbon in 1647. Luis Serrão Pimentel was a role model with his treatise *Arquitectura Militar e fortificação* (1659).[139]

[137] *Appendix C.1.4*, *Photographs 15*,*16*, similar to the wooden bracing shown in *Appendix C.2.1*, *Photograph 3.*
[138] (Farinha, J.S.B. 1997, 29-34, 87)
[139] (Rossa, W. 2002, 276)

2.3.3 Preliminary census of Lisbon's overhanging dwellings towards their safeguarding policy

A diachronic analysis, based on archival documents[140] and on-site surveys, clearly shows the variety of the causes of alteration and degradation of the Lisbon's overhanging dwellings. More specifically, these medieval houses have undergone considerable alterations as a consequence of, among others, fires, earthquakes, *Manueline* provisions, and the needs of their inhabitants. The main causes of the replacement of the timber frame walls over the centuries were the above-mentioned decree issued by King Manuel I ordering the substitution of the timber framework with brick walls,[141] natural causes (earthquake of 1755 and following demolitions by city planners), and the advent of concrete in the early 20th century. Additionally, the required improvement of living conditions since the late 18th century implied other alterations, such as the introduction of additional windows and changes in the internal layout.

Besides the difficulty to establish common rules to regroup these very heterogeneous buildings, countless causes of alterations have compromised their authenticity and integrity.[142] Archival data reports pathologies in most cases caused by a lack of maintenance and the degradation of materials, especially in the overhanging volumes, pavements, and the roofs.[143] Detached plaster, rotten timber structure, and water infiltration from the roof are the most cited pathologies.[144] In some cases, other causes of structural weakness are also attributed to the 1969 earthquake[145] or the construction of the underground public car park in *Praça Martim Moniz* in 1981. In particular, despite the limited range of the car park's impact (10.00 m), it affected a traditional block of overhanging buildings.[146] The Lisbon archival dataset also shows that high demand led to split the dwelling units from the 1960s, despite the very low living conditions and very limited space.[147]

On the other hand, considerable efforts were made from the 1970s to improve housing conditions and structural performance through a public campaign for social and urban recovery. A technical office, set up in 1985/86 and reorganized in 1990/1, was installed in *Alfama* district with several duties, i.e. inventory, sociological survey, and urban renewal planning strategies. Furthermore, a funding program *Regime Especial de Comparticipação na Recuperação de Imóveis Arrendados* (RECRIA)[148] was established in the late 1980s through which grants were awarded for up to 65% of the total cost of works.

A preliminary inventory of Lisbon overhanging dwelling revealed a wide range of situations, as shown in *Tables 2.02*, *2.03* and in *Figure 2.20*. *Dissonances* and *continuities* in the original construction and subsequent refurbishment can be analysed through comparison based on archival photographic data. In the framework of this research, *continuities* mean the survival of the main architectural features, as well as the internal and external configurations. *Dissonances* refer to adulterations caused by the introduction of elements that did not match the original construction, the local architectural lexicon or the historical stratifications. The replacement of the

[140] Miscellaneous records collected in the Lisbon Municipal Archives, i.e. dossiers listed in *Appendix B.1.1* and photograph documents.
[141] (CML 1957) One example survived by the *Manueline* legislation is indicated by (Carita, H. 1999, 83).
[142] Due to these several changes regrouping into a single group (labelled *Pré-pombalino*) according to the date of construction is almost questionable (Appleton, J. 2008, 396).
[143] Due to its steadily substitution, Carita states that no authentic roof can be found in the *Bairro Alto* parish, except that in the building *Rua da Rosa* no.143, beneath the new roof (Carita, H. 1994, 171,173).
[144] AML, PO 21940; AML, PO 34998; AML, PO 8956
[145] AML, PO 21285; AML, PO 32210
[146] AML, PO 13444
[147] e.g. AML, PO 11051; AML, PO 19343; AML, PO 20972; AML, PO 21285; AML, PO 21582; AML, PO 21713, AML, PO 21940, AML, PO 3217
[148] Special legislative system for reimbursement for the recovery of leased buildings.

traditional structures (e.g. internal partitions, floors, and roof), architectural details and traditional finishing (e.g. balconies, window frames) with modern construction systems (e.g. mixed structure of reinforced concrete and steel, acrylic or cement-based plaster) should be evaluated as dissonances given that these practices could invalidate the buildings' traditional value. On the other hand, alterations like mergers of plots, introduction of *Pombalino* windows or dormer windows and a few functional adjustments, may not be considered *dissonances* because they are part of the building's history and represent adaptations needed for basic living requirements.[149]

Table 2.02 – Degree of authenticity of the overhanging dwellings, as proposed in this research

DEGREE OF AUTHENTICY	(almost) TOTAL	PARTIAL	(almost) NAUGHT
Structural features	i) Original (or rebuilt in 18thC-19thC) overhanging half timbered wall ii) Original floor structure	i) Partial replacement of the half-timbered walls and reiforce by steel grid and cementium mortar ii) Partial replacement of floor structure	i) Replacement by concrete structure ii) Replacment of floor structure and new staircase and elevator shaft
Morphological and typological features	i) Maintenance of the building enviroment ii) Original volumetric composition iii) Original layout with some functional adjustment (i.e. timely interventions, sanitary installations)	i) Few changes of the building enviroment ii) Original volumetric composition iii) Several interventions in plan (i.e. partial or limited demolition, internal arrangements)	i) Several changes of the building enviroment ii) Few changes in the volumetric composition iii) Changes of the original distribution (i.e. demolition of the all of the internal walls, access systems and stairs position)
Finishing and architectural details	i) Original facade ii) Permanence of distinctive features (i.e. railing, chimney, door jambs, handrail, ceramic panel) iii) Compatible plaster in material composition and colour	i) Alteration of openings on the ground floor ii) Loss of few distinctive features iii) Compatible plaster in composition or no no compatible in colour (or vice versa)	i) Alteration of openings on entire facade ii) Loss of many distinctive features iii) Non-compatible plaster in composition and colour

In most of the cases analysed, the original volumetric configuration was preserved, probably because it is the main influential factor of the urban environment and collective memory. On the other hand, only a few of the original features remain: wooden painted planks, white double-hung windows, narrow balconies, and votive panels. [150] Additionally, there are frequent dissonant elements within the later intrusive refurbishments (replacement of infill frame walls with brick and reinforced concrete structure, alteration of the position of the openings on the main facade, profound typological changes).

The fundamental role of the community for the built heritage safeguarding was underlined since the *International Conference of Athens* in 1931, which points out the ethic character of the conservation policies.[151] The preservation of the built heritage over the centuries is a deliberate act that should be ripened through an enduring and broader knowledge[152] and appropriate operational strategies. This is true foremost for the traditional timber structures, whose resilience and structural reliability facing earthquake damage is a *rebus ipsis dictatibus*[153] in Lisbon as well as in other multiple cultural contexts.

When intervention works are required, the most important step in a preliminary analysis is understanding what are the *continuities* to be safeguarded and the *dissonances* to address.

As established in the Venice Charter (1964), the assessment of the structural authenticity is crucial for the conservation and rehabilitation of the ancient buildings: it is a key objective of refurbishment policies and for

[149] (ICOMOS 2003)
[150] Votive panels, executed by low- skilled craftsmen, were commonly applied in recent time on the main facade of old houses, as testified by the panel of 1930s in the medieval house in *Rua dos Cegos* nos. 20-22 in Lisbon.
[151] (IMO 1931)
[152] "(…) from the material culture to the technologies; from the spatial structures to the concept of habitation; from the cognitive system to the historical contexts; from the mediations between nature and culture of epistemology, freely bridging disciplinary fields and even redesigning them." (Prista, P. 2014, 8)
[153] i.e. dictated by the facts themselves

the listing of heritage.[154] The significance of the historical buildings depends on preserving "the coherence of the construction processes, the material dimension and the expressive solution".[155]

Table 2.03 – Lisbon's overhanging dwellings divided for degree of authenticity and state of conservation

DEGREE OF STRUCTURAL AUTHENTICY	(almost) TOTAL	PARTIAL	(almost) NAUGHT
Case studies	***Rua do Benformoso, 101-103*** ***Rua Achada, 23-25*** *Rua dos Cegos, 20-22* *Largo do Chafariz, 32-33-35-37* *Calçadinha de Sto. Estêvão, 1, Rua dos Remédios, 25-27*	*Rua da Galé, 13-15** *Rua das Farinhas, 32-34* *Rua da Regueira, 1-1A* *Escadinhas dos Remédios, 5-7* *Rua do Castelo Picão, 20-22, Beco da Cardosa, n.36** *Rua do S. Miguel, 61-63* *Largo do Chafariz de Dentro, 22-23* *Calçada de S. Vicente, 15-17* *Escadinhas de Sto. Estêvão, 1-5, Rua dos Remédios 41* *Rua do Chapelão, 2-4-6-8, Rua da Mouraria,80-82-86-90*** *Rua da Regueira,37, Beco das Cruzes, n.1* *Rua João do Outeiro, 9-11* *Calçadinha de São Miguel, 38-40, Rua do Capel Picão,6***	***Rua da Guia, 1/7**** *Largo de S. Miguel, 5, Rua S.Miguel 18-20* *Rua do Vigário, 2-4, Rua dos Remédios, 121** *Beco da Cardosa, 10* *Pátio da Cruz, 3-4, 11-15* *Beco das Canas, 3-5* *Rua de S. Miguel, 25* *Rua do Espírito Santo 2, R. de Sta. Cruz do Castelo, 15* ***Beco de S. Miguel, 17*** *Rua dos Remedios, 63-65, Beco Maria Guerra, 2* *Travessa de São Miguel, 9-11* *Largo do Chanceler, 3-3A* *Beco das Barrelas, 2-4* *Beco da Formosa, Pátio do Prior* *Rua do Benformoso 80-84-88-90***
numb.	5	14	15

STATE OF CONSERVATION	GOOD	MEDIUM	MEDIOCRE
Case studies	*Rua dos Cegos, 20-22* ***Rua da Guia, 1/7*** *Largo de Chafariz, 32-33-35-37* *Largo do Chafariz de Dentro, 22-23* *Calçada de S. Vicente, 15-17* *Rua de S. Miguel, 25* *Rua de S. Miguel, 61-63* *Rua dos Remedios, 63-65, Beco Maria Guerra, 2* *Travessa de São Miguel, 9-11* *Largo do Chanceler, 3-3A* *Rua João do Outeiro, 9-11* *Beco das Barrelas, 2-4* *Calçadinha de São Miguel, 38-40, Rua do Capel Picão,6*** *Rua do Espírito Santo 2, R. de Sta. Cruz do Castelo, 15* *Rua do Chapelão, 2-4-6-8, Rua da Mouraria, 80-82-86-90*** *Calçadinha de Sto. Estêvão, 1, Rua dos Remédios, 25-27* *Rua do Benformoso 80-84-88-90***	*Largo de S. Miguel, 5, Rua S.Miguel 18-20* *Rua das Farinhas, 32-34* *Beco das Canas, 3-5* *Escadinhas de Sto. Estêvão, 1-5, Rua dos Remédios 41* *Beco da Formosa, Pátio do Prior* *Rua da Regueira,37, Beco das Cruzes, n.1* *Beco da Cardosa, 10* ***Beco de S. Miguel, 17*** *Rua do Vigário, 2-4, Rua dos Remédios, 121** *Rua da Galé, 13-15** *Escadinhas dos Remédios, 5-7* *Rua de Castelo Picão, 20-22, Beco da Cardosa, n.36**	***Rua do Benformoso, 101-103*** ***Rua Achada, 23-25*** *Rua da Regueira, 1-1A* *Pátio da Cruz, 3-4, 11-15*
numb.	16	13	4

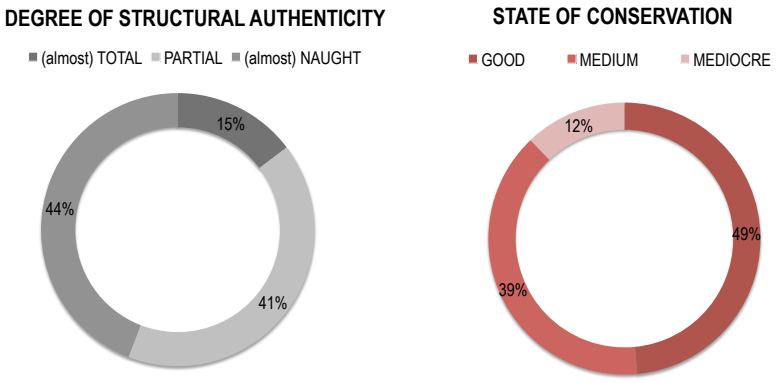


Figure 2.20 – Charts of degree of structural authenticity and state of conservation of Lisbon medieval overhanging dwellings

In medieval dwellings, the construction phases depended on the successive assembly of elements and the aggregation process occurred by means of a vertical juxtaposition of elementary spaces. Construction by juxtaposition could be analyzed in reverse, in order to understand the techniques and structural principles and to preserve the components.[156]

[154] (ICOMOS 1964) (Carbonara, G. 1997) (ICOMOS 2003) (Nezhad, S. F.; Eshrati, P.; Eshrati, D. 2015)
[155] (Zancheti, S. M.; Flaviana, L; Piccolo, R. 2009)
[156] (Giuffrè, A. 1993)

Several dissonances are irreversible. However, after the anamnesis, analysis of archival data and onsite survey, appropriate techniques could be used to restore the existing continuities and eliminate the weaknesses (intrinsic and added by inadequate alterations). Based on the above premise, the principles for safeguarding this building type relate to: (i) structural system; (ii) typological and morphological features; and (iii) finishing and architectural solutions.

(i) *structural system*: For the evaluation of the structure (that should fulfill the requirements of strength and stability, serviceability, and durability) a detailed on-site assessment related to the state of conservation of the members (e.g. pathology, residual cross section, and density) and the assessment of carpentry joints, is required.[157] Depending on the state of conservation, the reinforcement project entails establishing priorities as to whether dissonances/continuities should be preserved or discarded.

It is worth noting that the conservation and strengthening intervention should assure solutions that are compatible with the original structure, as highlighted in the literature and in current municipal regulations.[158] It might include the replacement of damaged parts, and these should match the original component as closely as possible in material, design, species, grade, grain, dimensional stability, decay resistance, and environmental impacts. Traditional techniques and local materials are preferable, [159] together with treated timber, whose average water content is 12% (e.g. Maritime Pine, Chestnut, or Nordic Pine in autoclave), infill with lay bricks and lime mortar.

On the other hand, reinforced render applied on both sides of the infill frame wall by means of mortar with low retraction or project reinforced shotcrete represent the current reinforcement techniques (e.g. AML, PO 21940), as described in the literature.[160] The main drawback is that the grout has a cementitous base, which may cause local areas of stiffness, loss of ductility, and salt crystallization. Accordingly, the abovementioned technique invalidates the specific properties of timber frame walls and introduces pathologies due to physical, chemical, and mechanical incompatibility.[161]

Another aspect regards the compatibility of materials when using FRPs and resins (or even metal plates) to avoid inducing moisture concentration but which allow an exchange of humidity with the external environment to prevent an acceleration of decay (e.g. biotic attacks).[162] Additionally, chemical interactions between materials (strengthening component and timber as well as any treatment of timber) have to be considered. For example, fungicidal treatments (based on metal salts) could corrode steel components;[163] the presence of tannic and acetic acid in oak could also cause corrosion in mild steel; the use of resins may cause condensation at the repair/timber interface and if used for an external repair they may be damaged by ultraviolet light.[164] The new structure can adapt to the original part of the structure if the contemporary interventions respect the same strength and ductility of the original construction system.

(ii) *typological features*: The original layout generally does not comply with national regulations and current living standards. However, a flexible attitude should be taken to these requirements which should be

[157] (Cruz, et al. 2015)
[158] (CML 2010)
[159] (Appleton, J. 2003)
[160] Ibid. (Coías, V.C. 2007)
[161] (Gonçalves, A.M.; Gomes-Ferreira, J.; Guerreiro, L.; Branco, F. 2014)
[162] (CNR-DT. 201/ 2005)
[163] (Beckmann, P.; Bowles, R. 2004)
[164] (Pender, R.; Ridout, B.; Curteis, T. (eds.) 2012)

adapted to the original construction; moreover, the minimum intervention criterion should be respected.[165] It is advisable to avoid constructing (or enlarging) windows (or door-windows) especially in the main facade, introducing balconies and installing lifts.

(iii) *finishing and architectural solutions*: As stated by Lisbon Municipality, the replacement of timber railing, and other traditional features of medieval buildings is forbidden.[166] In compliance with international guidelines, the removal of timber planks that protect the intrados of the overhang structure (e.g. *Beco São Miguel* no. 15) should also be avoided. Periodic checks and maintenance operations should also be conducted due to the high level of decay of materials. A detailed analysis of the original colours and material compositions should be mandatory. The facade-finishing colour should be carefully assessed during regular on-site survey. The appropriate colour should be decided on a case-by-case basis, supported by historical studies and avoiding uncritical solutions. As suggested by archival photos and an on-site chromatic analysis (e.g. mediated by *Natural Colour System-NCS* in *Largo do Chafariz de Dentro*),[167] the original plaster was white or cream in contrast with the green or orange water washed of the corner walls and the timber planks covering the intrados of the overhanging volumes, and with the timber railings and *muxarabi* which are traditionally dark green (*bottle green*).

The chromatic value of historical houses should be preserved as crucial factor of the urban image to convey the community's sense of belonging to the city.

[165] (ICOMOS 2003)
[166] (CML 2006a)
[167] (Bissau, L. 2012)

2.4 Final comments

The 1755 great earthquake in Lisbon is commonly viewed as a watershed between two different epochs. The radical difference between the late-18th century regular plan of the downtown Lisbon and its former layout as mapped by João Nunes Tinoco in 1650[168] catches the eye as a measure of the extent of the *Pombalino renewal*.[169] This renewal of Lisbon has left a strong mark on Portuguese society beyond its urban perimeter. Several aspects were discarded and forbidden in the renascent city, such as the irregularity of the buildings in plan and elevation, narrow streets, high verticality, as well as the overhanging volumes.

However, continuities between these epochs can be retraced by following clues of cultural permanence in physical and intangible terms. As stated by Parrinello:

> "The historical outcome of an earthquake is a blend of ruptures and continuities, sometime very evident, sometimes more subtly dispersed in the tapestry of the historical fact. Historians should unravel these different threads if they want to let earthquakes speak in their stories. To read the traces of the earthquakes in the complex text of the historical change, what happened before the earthquake is just as important as the aftermath."[170]

In reformulating the critical view of the *Pombalino* programme, França claims the independence of this renewal from foreign influence. This idea is justified by the exceptionality of the context and by considering the lack of transmission of the experiences gained in Europe, while admitting that Mardel – Hungarian born – and Marquis of Pombal knew the political and physical contexts of London, Paris, and Vienna.[171]

As underlined in literature, this rebuilding process was deeply rooted in the bylaws issued during the *Manueline* epoch and arose from the recovery and improvement of local features. The urban planning involved a set of *inventions* according to its etymological sense (*inventio* from *invenio*), reformulation of existing models or solutions.[172] Lisbon's reconstruction can be viewed as the end point of a long process arising from post-disaster observations as well as from the pragmatism and well-grounded military experience of the town planners. The elements of this cultural continuity, which converged into a local seismic culture, encompassed urban principles (regular allotment, permanence of the location of the two former squares) and technical solutions (timber-framed system, ground foundation). The principles of reform underpinning Lisbon's rebuilding may be identified in the city's own history and culture.

As a matter of fact, looking back at the history of urban planning in Lisbon during the Age of Discovery, the endeavour of the central authority for rational urban renewal was affirmed long before the 18th century, as shown in the enlargement of the main streets and the allotment of *Bairro Alto* district.

On one hand, the 1755 catastrophe accelerated a necessary process aimed at a consistent reshaping of

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[168] *Planta da cidade de L[isbo]a em q se mostrão os muros de vermelho com todas as ruas e praças da cidade dos muros a dentro co as declarações postas em seu lugar.* Compiled by João Nunes Tinoco, Architecto de S. M[a]g[esta]de anno 1650. [approx 1:3100], 1000 *palmos* = [7.20 cm] at Lisbon: Lith[ographia] da Imp[rensa] Nac[ional], 1853. plan: black and white lithografy; sheet 58.00 x 75.00 cm. [online] http://purl.pt/4503/3/.

[169] This is the term employed by Manuel da Maia in the first part of his *Dissertação* (França, J. A. 1987, 311).

[170] (Parrinello, G. 2015, 6)

[171] (França, J. A. 1987)

[172] Barreiros refers to the *innovations* of Lisbon (Barreiros, M.H. 2009). By invoking Vitruvius's thought, Strappa explains that *inventio* is a critical discovery rather than a programmatic innovation (Strappa, G. 1995, 27,45).

this capital. The urban layout of Lisbon had been mostly characterised by compact overhanging dwellings and overcrowded streets, "in which the wood prevails on the mortar and the sudden prevails on the common sense"[173] would have been surpassed in any case by modern requirements of the new emerging class. Accordingly, the reconstruction of Lisbon was an opportunity to reshape the central core in order to better integrate the waterfront square – which was already "the aquatic gateway to a global world" in King Manuel's thought[174] – into the urban fabric and to cope with the structural safety, transit and hygiene problems of the former settlement.

These works show that the planning and construction references were deeply rooted in the local tradition and previous practice. Humble medieval wooden houses, based on masonry walls on the ground floor, embody *in nuce* the construction principles that would be reformulated in the new city. Amongst many houses built prior to the 1755 earthquake in Lisbon, whose external walls (on the upper floors) and internal partitions are composed of a timber frame skeleton, particular attention should be paid to the overhanging dwellings.

The overhanging dwellings clearly exemplify the technical continuity of the use of composite load bearing systems in Portugal. Their structural efficiency is due to the reduction in the weight from the lower to the upper floors, the ductile behaviour, and the connections between the infill frame and the floor structure by means of carpentry or nailed joints. Pre-1755 ordinary houses in the historical parishes of Lisbon (*Alfama*, *Mouraria*, *Castelo*) included irregular layouts in their plots and construction system. However, in view of long periods of neglect and difficulties in making reliable behaviour assessments, they are today considered seismically vulnerable. In this work, strengths are discussed by analysing the existing case studies, whose main features are deduced by comparing archival documents (iconographic data and requests by owners for council's approval) and the *status quo* of the dwellings.

Recognising the cultural and technical value of this building type, a preliminary survey of Lisbon's overhanging houses was carried out in this study through archival dataset and on-site analysis in order to identify their distinctive features and also to assess their degree of authenticity and state of conservation.

For a number of reasons, less than 15% maintain their structural and/or architectural authenticity, in the sense that their rehabilitation works have involved less intrusive works by employing compatible or similar techniques and by safeguarding the original layout and lexicon in some way. The analysed case studies clearly show that when interventions were executed in order to restore an entire construction or change its use, this commonly and sadly caused a loss of authenticity. It should be underlined that the presence of overhanging volumes or traditional features (balcony, votive panel), as well as location in an old area of the city, do not constitute sufficient evidence of architectural or structural authenticity.

However, the preservation of the authenticity of this building type should be a key aim of policy strategies for keeping historical memory alive and for avoiding further inappropriate rehabilitation and retrofitting solutions. Therefore, guiding principles for safeguarding their structural features, typological features, finishes and architectural details were delineated in the last section (*section 2.3.3*).

Future research could investigate the material characterisation of this vernacular building type by including e.g. the provenience of the raw materials of these buildings. Seismic assessments of the examples that still maintain their structural authenticity could be the basis for their appropriate rehabilitation.

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[173] "tentemos de imaginar a sucessão acidentada de alçados irregularmente alinhados, avançando sobre a rua em sacadas, muxarabis, balcões, *predominando a madeira sobre a cal e o improviso sobre o senso*." (Rossa, W. 2002, 225)

[174] (Gshwend, A.J.; Lowe, K.J.P. 2015, 30)



CHAPTER 3 – Town-planning and building practice in Calabria after the 1783 macro-earthquake

3.1 Introduction

Over than thirty thousand lives were lost in the southern provinces of Italy (Calabria) due to a strong seismic sequence less than thirty years after the 1755 earthquake of Lisbon.

In comparison to Lisbon, the body of research on the post-seismic reconstructions in Calabria has room for improvement. However, failures of modern concrete construction systems have refocused attention on these historic settlements and their response to this disaster. Despite this renewed scholarly interest, gaps in the literature still exist, especially regarding the architectural and construction systems of the late 18th century aimed at preventing losses of life and large-scale damage to buildings.[1]

In this chapter, Calabrian reconstructions[2] shall be traced on the basis of two research works published by Maretto in 1975[3] and by Principe the following year. Their scholarly merits are manifold. Maretto's research is the first notable fieldwork intended to shed light on the physical reality of sixteen (fully or partially) reconstructed towns (light blue in *Figure 3.01*). A mutual comparison between them and a comparison of each with its respective original plan is made by overlaying maps and by analysing architectural and typological results.

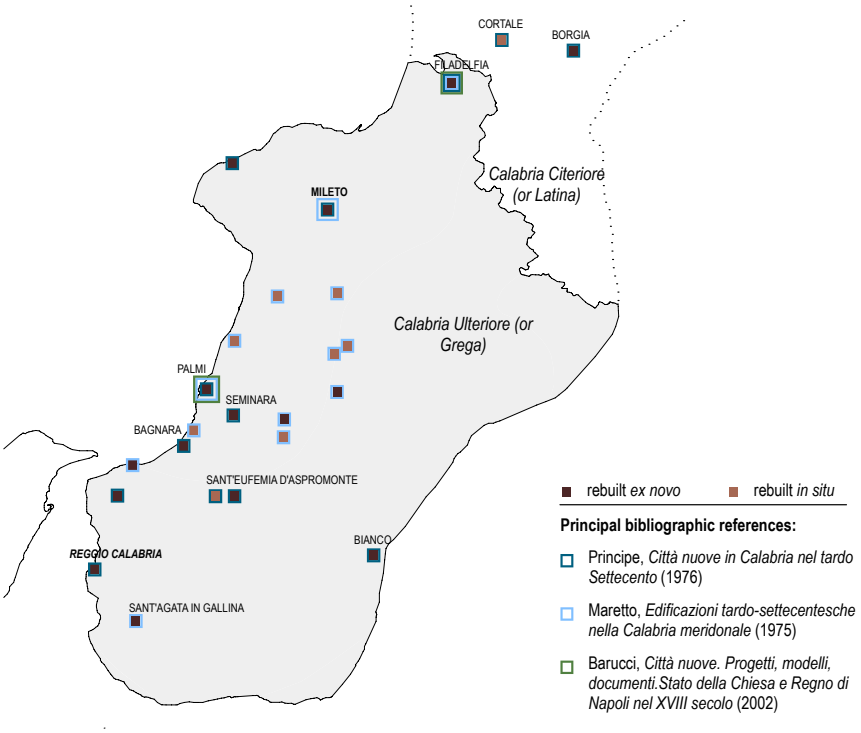

Figure 3.01 – Calabrian map: overview of bibliographic references on major rebuilt towns (© S. Stellacci)

[1] In an expressive metaphor, Principe portrays the lack of interest in Calabria as a "great white stain" on the cognitive-technical map of Italian history (Principe, I. 1976, 21-24).

[2] Only the largest rebuilt centres shall be discussed, leaving out smaller agglomerations. The list of towns, damage, and strategies to be implemented according to Vivenzio are published by (Principe, I. 1976, 53-70). Many other minor towns are discussed after the earthquake by Baratta, divided into geographical zones, i.e. provinces of Reggio, Catanzaro, and Cosenza (Baratta, M. 1908).

[3] Maretto organises on-site surveys carried out by his students (academic year 1968-69) at the then-recently founded University in Reggio Calabria (Maretto, P. 1975, 13-27), following Saverio Muratori's approach from twenty years earlier. This research was published as a monograph of the magazine entitled "Studies and architectural documents" (Ibid.)

Principe has yielded a clear picture of this complicated scenario by going beyond the typical framing of the *Southern question,* the political issue in whose light historical events of southern Italy are generally investigated and judged.[4] Principe, instead, analyses fifteen centres (blue in *Figure 3.01*), whose ideal outlines are mapped in the annex to *Istoria* (1784), which was published by Neapolitan Royal Academy of Sciences and Letters.[5]

Principe's research, grounded on an extensive literature review and archival documents,[6] notes the priorities under consideration for each historical phase and evaluates the resulting urban tissue. This scholar highlights the correlation between specific local constraints and the genesis of the human settlements and discusses how these were shaped according to the requirements of different social classes, frequently in contrast with the purposes of the central authority.

The analysis below shall attempt to conciliate the (often discordant) observations of these two scholars and to better understand the construction system employed during the post-seismic reconstruction in comparison to Vivenzio's anti-seismic house and the legislative requirements of 1784. Parallels are drawn to Lisbon when appropriate.

This research reflects some lack of background knowledge (e.g. the analysis of the local housing plots pre-earthquake) and has also been hampered by some difficulties encountered during the fieldwork study. These adverse factors owe to the large territorial extension of the *Borbone* program and the dispersed and peripheral locations of the rebuilt tissues. Many original features of the building stock have also been compromised by various intervention works from the early 20th century due to further earthquake damage and the absence of specific safeguarding provisions. During the on-site surveys – in most cases in private properties – other difficulties arise from the position of the timber skeleton in the structure wall (i.e. it is hidden) and the existence of multiple construction systems in this epoch to satisfy the demanding legislative provisions. By contrast, the analysis done for Lisbon was able to draw on well-established literature on this historical phase and was aided by a certain homogeneity found in both the architectural and construction models.[7]

Given the extent of this subject matter, the scope of this research shall be narrowed to a specific case study, Mileto, a new centre rebuilt few kilometres from the medieval town.[8] At first glance, choosing Reggio Calabria might have seemed more logical for comparison between *Borbone* and *Pombalino* reconstructions – both Reggio and Lisbon were the most important cities of the respective kingdoms, organized according to a linear pattern (due to proximity to the waterline),[9] with post-seismic rebuilding *in situ*. Both cases included the full demolitions of unscathed buildings and needed to solve many controversies arising from the assignments of the building lots to private owners. However, the late 18th century urban and building tissue of Reggio Calabria

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[4] This is known as *questione meridionale*. In the introduction to Principe's book, Pardo emphasizes "(…) the sense of the novelty of issues dealt with by taking into account the previous knowledge on the national territory subject to the Borbone state at this time". *Ita*: "(...) il senso della 'novità' dei temi trattati rispetto alla conoscenza che allora si aveva del territorio nazionale soggetto allo stato borbonico")(Principe, I. 1976, 14).

[5] See footnote 58

[6] *Suprema Giunta di Corrispondenza della Cassa Sacra* in *Archivio di Stato di Napoli* and *Cassa Sacra dell'Archivio di Stato di Catanzaro*.

[7] This homogeneity can be grasped in this Lisbon district, despite the largest amount of buildings executed in this period and their slight differences (see *Chapter 5*, *sections 5.1*, *5.2.1*).

[8] Causes and philosophical debate related to the 1755 and 1783 earthquakes and the following natural disasters (e.g. tsunami, wildfires, landslides) are not extensively discussed because they are beyond the research foci.

[9] Parallels can be drawn in how both cities are situated at extreme points of their landmasses: Lisbon is the most western coastal capital in Europe, and Reggio sits at the head of its peninsular system (Cataldi, G. 1974, 169).

underwent major changes following the 1908 earthquake and other interventions, and these factual conditions complicate any comparison based on architectural artifacts.

Among various towns rebuilt in this period, the reasons for choosing Mileto as focus are multiple. Firstly, the leading city planners called to plan Reggio Calabria, Winspeare and La Vega, were also entrusted with the definition of the layout of new Mileto, in spite of the fact that, this city being nearby Monteleone (the administrative seat of the Vicar General to this province), it should have been planned by other local technicians. As outlined by Zinzi, the Neapolitan reconstruction activities were centered around the following hubs: (i) the most naturally fertile lands, i.e. two lowlands on the Tyrrhenian coast – Sant'Eufemia and Gioia Tauro – [10] and the hilly lands surrounding Poro mountain; (ii) in between Ionian and Tyrrhenian coast; (iii) along the coastline; (iv) along the *Strada Regia delle Calabrie,* which connected Vesuvian settlements, or along Isthmian routes. Mileto belongs to the first group, since it is located on the east side of Poro Mountain.

It is likely that Mileto was regarded as reference model for the other towns to be reconstructed from scratch,[11] whether *in situ* or *ex situ*. The clear readability of the historical centre in spite of its recent urban expansion can also explain the interest of several scholars whose knowledge contributes a basis for this research.[12]

Beyond these considerations, Mileto was also selected in order to narrow the scope of this research by analysing a specific timber-framed building at the geometric and symbolic centre of its reconstruction, the Bishop's Palace.

[10] (Zinzi, E. 1994, 89)
[11] (Principe, I. 1976, 164)
[12] (Baratta, M. 1908, 182-187) (Cataldi, G. 1974, 151-153) (Maretto, P. 1975, 148-155) (Principe, I. 1976, 250-261) (Barucci, C. 2002)

3.2 Town-planning and construction systems prior to the 1783 macro-earthquake in Calabria

Because the 1755 earthquake heavily damaged Lisbon, the insight into the pre- and post- scenario has been above mapped through an urban-scale analysis. Conversely, as the damage and consequent reconstruction activities following the 1783 earthquake in Calabria took place at the regional level, these historical facts shall be analysed at territorial scale by discussing some relevant contextual features.

Environmental traits prior to the 1783 earthquake shall be briefly delineated, considering "the geographic territory not only as a support for the performance of those activities by which its morphological aspects tend to be described, to specify parameters and quantitative and static values, to provide information on climatological, hydrological, orographic, settlements etc." but "also as a temporal, therefore historical, subject of particular types of transformations".[13] Following Saverio Muratori's reflection, the territory should be understood as "global architecture" and a result of the combination of a law of permanence and a law of cyclicity.[14]

3.2.1 Geographical and historical discontinuities

Calabria encompasses a multifaceted territory; it is mostly mountainous with two narrow coastal slopes – the low, sandy Ionic coast *vs* the high, rocky Tyrrhenian coast[15] – separated by the Apennine Mountains, where *La Via Grande* (*The Great Road*) has formed the unifying axis of many civilisations[16] (*Figure 3.02*). This region has been also subject to repeated and severe alterations over the centuries.

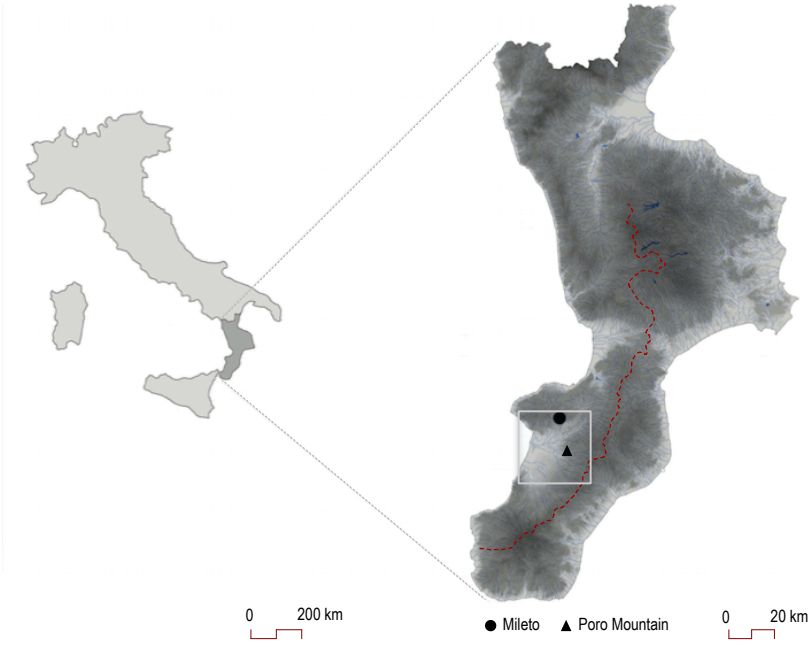


Figure 3.02 – Calabria region map and location of Gioia Tauro plain and of Mileto (© S. Stellacci)

[13] Comment by Pardo on Principe's work: "il territorio geografico non solo come supporto allo svolgimento di attività delle quali si tende a descrivere aspetti morfologici, a precisare parametri e valori quantitative e statici, a fornire notizie relative a caratteri climatologici, idrologici, orografici, insediativi ecc." ma "anche come soggetto temporale, perciò storico, di particolari tipi di trasformazioni". (Principe, I. 1976, 13)

[14] (Muratori, S. 1967)

[15] Asymmetry arises from the morphology of the Ionic coastline, low and regularly crossed by small waterways (*fiumara*), as well as the high and jagged Tyrrhenian features, with few landings, among which is the Gioia Tauro plain (Cataldi, G. 1974, 128).

[16] The Apennines route is identified as *La Via Grande* (*The Great Road*) in the IGM map (red line in *Figure 3.02*) (Cataldi, G. 1974, 29-30). Prehistoric migrations support the hypothesis that the Apennine Mountains are "the great unifying land route of ancient Italy". *Ita*: "la grande via di terra unificante dell'Italia antica". (Maretto, P. 1975, 111)

The complex geo-morphological setting and the unfavorable events – various occurrences and recurrences of history – [17] in Calabria have strongly affected its local history. These can be viewed as elements of structural discontinuity, real moments of rupture or times of crisis.

The majority of the towns are characterised by limited extent and by territorial dispersion. The morphological features of the territory (e.g. soil features, topography, and climate) were significant structuring factors for these settlements. The hierarchical socio-economic system – i.e. man-made structuring – was also influential in the development of the human settlement. With more specific reference to the 18th century phase, Principe notes that the continuous "search for an outward stability" of the population "was compromised and undermined more by specific class relationships rather than by terrible physical upheavals."[18]

Table 3.01 summarises Cataldi's analysis of the regional settlement forms, based on a critical evaluation of how these relate to historical events under distinctive civilisations. It follows Muratori's "theory of ridgelines", according to which the initial structuring of an environment would be travelling across a territory on the ridgelines. These paths can be divided into the more important highways – continental or peninsular – used as routes of flow migration – and their lateral secondary routes, which ended in the promontories at the confluence of two rivers. This initial phase is followed by the so-called phase of "mezza costa" ("half-coast"), when the paths orthogonal to secondary ridgelines are taking shape; the main centres on the promontory are connected through an anticline, which is reinforced by a manmade walls and is located at a lower altitude than its own principal ridgeline. in this phase the ridgeline loses its function as a unifying element of the "comb"system settlement".[19]

Table 3.01 – Synoptic table adapted from (Cataldi, G. 1974)

Summary oveview		**Territorial degree**			
		Spontaneus civilisations		**Planned civilisations**	
Development civil aspects	old cycle	Protohistoric civilisations prior to 2000 BC	Italic civilisations 2000-1000 BC	Ancient greek civilisations 100-200 BC	Roman civilisation 200 BC- 400 AD
	modern cycle	from the Byzantines to the Normans 400-1000 BC	from Normans to Angevins 1000-1300 BC	from Angevins to Bourbons 1300-1700	from Bourbons to modern epoch 1700-1900
Development territorial aspects	phases	**1st PHASE: creation**	**2nd PHASE: consolidation**	**3rd PHASE: reutilisation**	**4th PHASE: riconsolidation**
	evaluation	process-triggering: inefficient	development of the process: understimated	climax of the process: efficient	crisis of the process: oversized
1.	**Territorial systems**	place with highest typical features	district of maximum sistematicity	regional of maximum organicity	national of maximum specificity
2.	**Pathways**	unifying ridge path dividing ridge path	anticlines unifying ridge path	cutting riverside	highway current road system
3.	**Tissues**	mountain slopes	hillsides	low valleys	reclamation
4.	**Settlements**	in sporadic aggregations in series	in systematic aggregations in series	in organic-episodic aggregations	in organic-total aggregations
Urban degree	original settlements linked to the need of habitations	within the promontory existing and disappeared	welding	coastline foundation (disappeared)	**late 18th century (new foundation)**
	linear settlements linked to requirements of growth	linear along ridgelines	linear along anticlines	long road (cutting)	coastline
	nodal settlement linked to trade requirements	placed on a saddle	cross-road	nodal (high altidues)	nodal (in the plain)
	head-settlements linked to qualyfing requirements	placed on the ridgelines existing and disappeared	placed on the anticlines	head anti-peninsular	head* (peninsular)

[17] (Gambi, L. 1965, 107)
[18] (Principe, I. 1976, 22)
[19] (Muratori, S. 1967) (Cataldi, G. 1974) (Caniggia, G.; Maffei, G. 1993, 210-221)

Turning to the Calabrian territory, four main phases within the lowland of the Southern area, i.e. the plain of Gioia Taro, are mapped out by Cataldi as shown in *Figures 3.03*, *3.04*.[20]

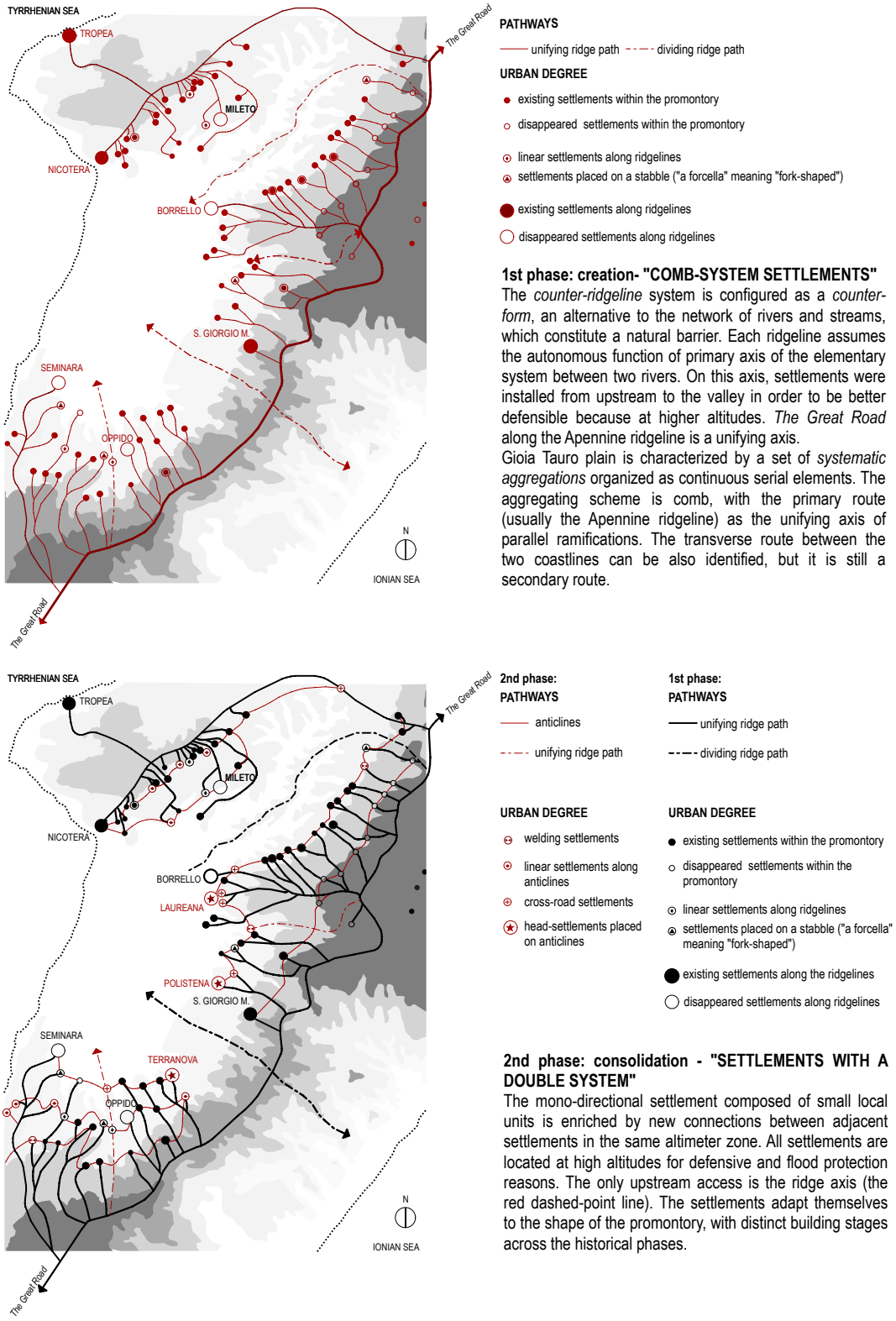
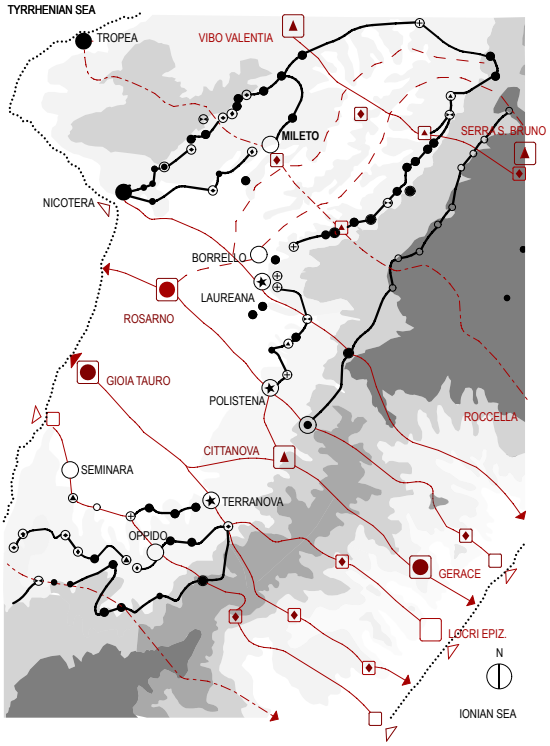


Figure 3.03 – Physiography of Gioia Tauro Plain: 1st /2nd phases, adapted from (Cataldi, G. 1974, 26, 57) (© S. Stellacci)

[20] In each phase, the scheme of the territorial phase is overlaying in red to the previously phase, which is instead identified in black, as drawn by Cataldi (Cataldi, G. 1974, 57).



3rd phase:

PATHWAYS

- cutting ("taglianti")
- riverside

URBAN DEGREE

- coastline foundation settlement (disappeared)
- long road settlement (cutting) ("di lungo percorso taglianti")
- nodal settlement placed in high altitudes
- head anti-peninsular settlement

previous phases:

PATHWAYS

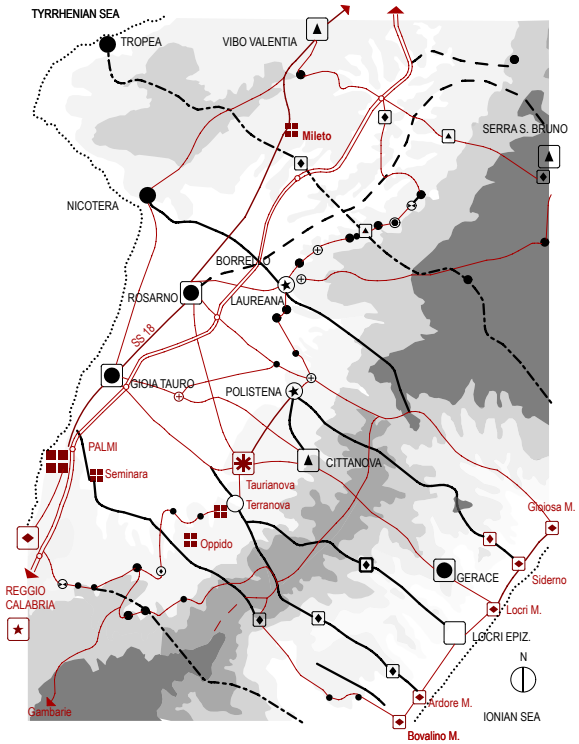
- anticlines
- unifying ridge path

URBAN DEGREE

- welding settlement
- linear settlement along anticlines
- cross-road settlement
- head-settlement placed on anticlines
- linear settlement along ridgelines
- settlement placed on a stabble
- existing settlement along ridgelines
- disappeared settlement along ridgelines

3rd phase: reutilisation - "COUNTER-PENINSULAR SYSTEM"

Coastal areas that had remained as far as unpopulated because geologically unstable became the crossroads of different civilizations, in conflict with each other. The occupation of the territory is being expanded and coast-to-coast connections are created for commercial purpose at the most favorable place. On the coasts, therefore, there are centers that become more prevalent than the previous ones. The Greek colonization from the south-east to the north-west comes from the Middle Ages onward but in the opposite direction.



4th phase:

PATHWAYS

- highway
- current road system

URBAN DEGREE

- late 18th century foundation
- coastline settlements
- nodal settlements of the plain (Piana di Gioia Tauro)
- head-settlements (peninsular)

previous phases:

PATHWAYS

- anticlines
- unifying ridge path

URBAN DEGREE

- welding settlement
- linear settlement along anticlines
- cross-road settlement
- head-settlement placed on anticlines
- linear settlement along ridgelines
- settlement placed on a stabble
- existing settlement along ridgelines
- disappeared settlement along ridgelines
- long road settlement (cutting) ("di lungo percorso taglianti")
- nodal settlement placed in high altitudes
- head anti-peninsular settlement

4th phase: riconsolidation - PENINSULAR SYSTEM

Similar to what occurred during the 2nd phase, longitudinal connections prevail based on the Roman road system. The current highway (SS 18) corresponds to the *Borbone* road, *Regie Poste*, which allowed the access from Naples to Calabria region.

Figure 3.04 – Physiography of Gioia Tauro Plain: 3rd/4th phases, adapted from (Cataldi, G. 1974, 87, 127)(© S. Stellacci)

All settlements and routes[21] are classified according to a *territorial degree* (i.e. historical sequences divided according to civilisation or governmental authority) by distinguishing *spontaneous civilisations* and *planned civilizations*, and according to an *urban degree*. This latter classification of the settlements refers to the predominant causes underpinning each settlement's foundation (or consolidation), e.g. related to the growth of trade or other circumstantial requirements. Moreover, the settlement systems and the routes are classified according to aggregation models. These routes may be located on a promontory or may follow a ridgeline, and they may be classified, e.g. as nodal, joining, etc.

In order to gain insight into the connective and settlement systems in the zone most affected by the 1783 earthquake, researcher Murru and the author of this thesis[22] extend an overview from the plain of Gioia Tauro to the entire southern region. Four historical phases can be identified before the urban reconstruction following the 1783 earthquake (*Figure 3.05*).

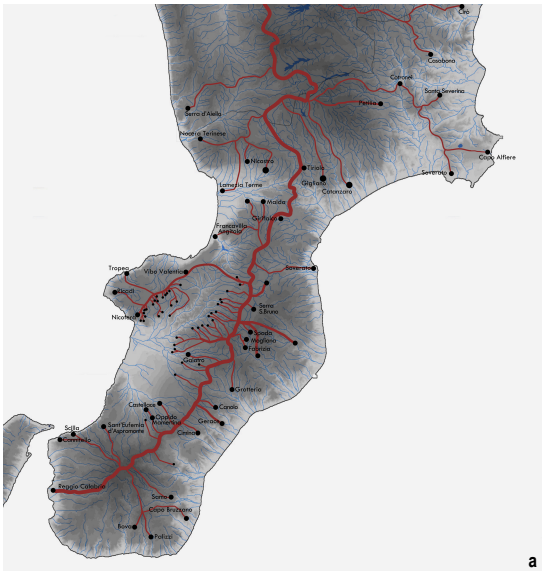
The analysis of the earliest territorial phase, from the Neolithic to the Bronze Age, shows that the oldest settlements were located on the Apennine ridgelines and secondary ridgelines, which can be classified in two types: *clusters* (along a ridge that reaches the sea level from a high altitude) or *comb* (on a ridge on the same altitude). These settlements were laid out in a pattern strictly correlated to the hydrographic network. Each secondary ridgeline, axis of the basic system included between two rivers, was the main path that generated its settlements, the earliest of which were located in the higher altitudes for defensive reasons (*Figure 3.05a*).

The second territorial phase, corresponding to the first Greek colonisation, dates back to the 7th century BC. The earlier unidirectional model of the settlements evolved at this point into a bi-directional structure. New paths of the hillside or *counter-ridge* were also routed through hubs at intersections with the ridge paths. These were trading and commercial points, as well as places devoted to public functions. Thus, a shift in settlement development occurred from the path of the ridgeline to the *counter-ridgelines*[23](*Figure 3.05b*).

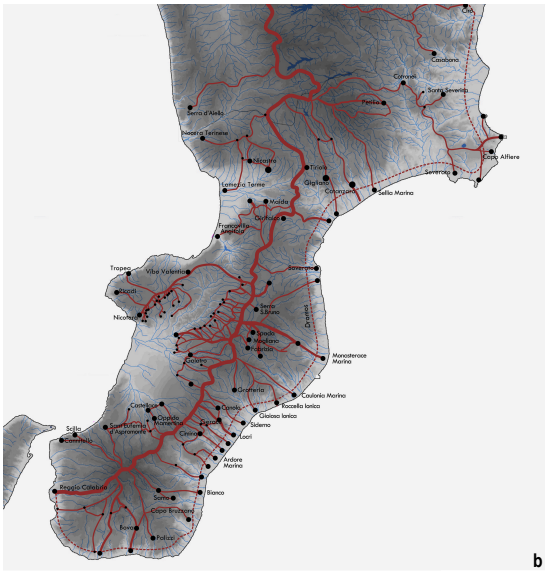
[21] The reading of the urban road system is based on a triad of routes. As a spontaneous or planned axis, the *primary route* (*percorso matrice*, literally *matrix route*) is a pre-existing route, whose function is to activate and influence the alignment of new building tissue. It is straight in order to shorten the path between important points. *Routes of the system* (*percorso di impianto*) are normally orthogonal to the primary route from which they branch out. *Routes for connection between routes of the sytem* (*percorso di collegamento tra percorsi di impianto*) are result from the development and consolidation of urban tissue in a given area (Caniggia, G.; Maffei, G. 1993).

[22] (Murru, S. 2016)

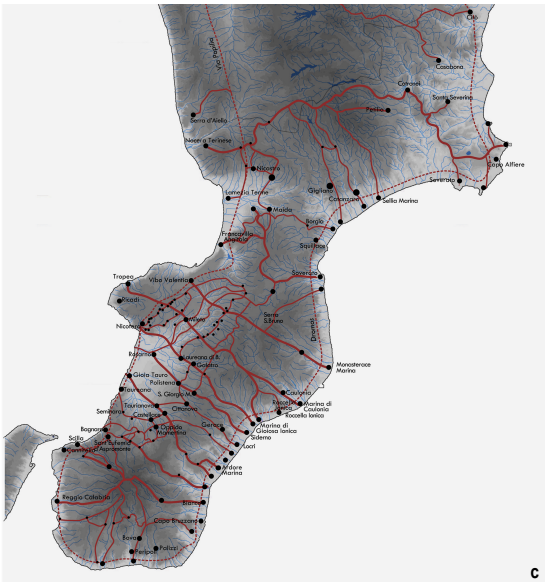
[23] Counter-ridges are the transversal connections between similarly-sized headland settlements, located on the heads of secondary ridges. From the morphological point of view, counter-ridge is a hallway up (or down) the slope that overlooks the valley bottom (Caniggia, G.; Maffei, G. 1993).



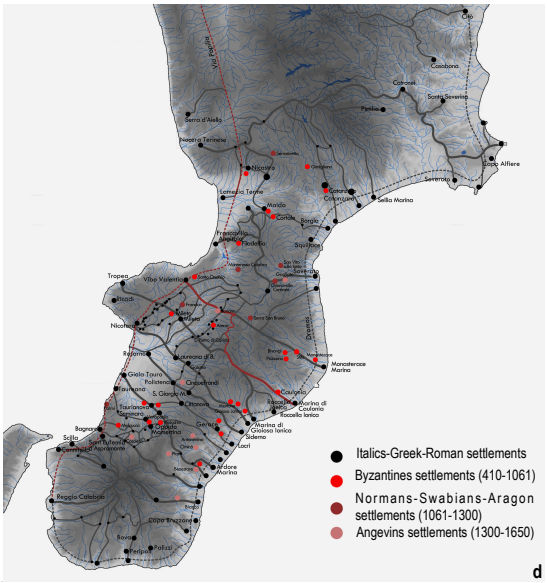
Bronze Age (1600 BC): The structure of the territory is mono-directional and based on a primary routes (*percorso matrice*) set on the Appenine ridge and the paths of ridge orthogonal to it. They are shaped as cluster or comb, where each ridge is an elementary system between two rivers. Headland systems (or the head of a secondary ridge) prevail. The expansions of these centers are executed linearly along the axis of a ridge. When headland settlements and linear settlement are joining, fork-shaped settlements.



Magna Graecia and first Colonies (8th BC): The structure of the territory becomes bi-directional (reticular structure). The areas with the highest concentration of settlements are half-coast or coastal: settlements located in the same altitude are connected through counter-crest paths (or orthogonal to the previous ones), along which the towns expand linearly. New settlements are established at the points between the ridge and the counter-ridge and along the coast (especially Ionic coast) and connected by a rout called *Dromos*.



Second colonies and Roman colonies (3rd century BC): The colonization of the Tyrrhenian coast and the long-river or valleys coastline is due to the penetration from the southeast to the northwest, along the riverside courses (called *Stenopos*). These cross the Apennine ridge in the most favorable valleys (second reticular structure). The Roman colonization influences the definitive shift from the Ionian coast to the Tyrrhenian coast due to the completion of *Via Popilia*, which connected Rome to Reggio Calabria.



Byzantine and Angevins Domains (410AD-1650): A gradual abandonment of the coasts starts from the Middle Ages. Coastal settlements move to new half-way inland. The settlements are isolated at high altitudes and often located at the nodal point between the anti-peninsular route and the half-coast route. Some anti-peninsular routes of Greek origin are reused, but in the opposite direction, i.e. from northwest to southeast. The Roman main road, *Via Popilia,* remains as the unifying structure.

Figure 3.05 – Calabria settlements and their historical phases prior to 1783 macro-earthquake (images from Murru, S. 2016) (© S. Stellacci)

It was with the foundation of numerous Greek colonies in this second phase that the Ionian coast became of primary importance. The coastal path known as *Dromos* represented an important access for these new settlements. This route still partially exists today, being slightly set back from the Ionic state road.

The third phase includes the second generation of Greek and Roman colonies (3rd century BC). During this phase, the most important area was that of the coastal strips – rivers and valleys – connected through the

routes, which crossed the peninsula from the southeast to the northwest. The settlements of this time assumed a reticular structure. In 132 BC, *Via Appia,* developed between two important towns – Capua and Reggio Calabria – known as *Via Popilia* (later *Via Regia*) was extended to the Tyrrhenian side by connecting some segments of the Magna Graecia network. Due to this easy connection and taking into account the fact that the Ionian coast, after its deforestation, had become marshy and more prone to the diffusion of some illnesses (e.g. malaria), the Tyrrhenian surpassed the Ionian coast in importance.

In the 5th century this area was subject to great historical and political upheavals, resulting in the movement of the population to safer, less-accessible places. The displacement of the former inhabited towns towards the inland and the intensive deforestation in this fourth phase produced further significant alterations of the settlement system and hampered its connections (*Figure 3.05c*).

Interestingly, the defensive solution adopted by local communities in many cases did not include the execution of the sort of town walls common in most coeval towns in Italy, but consisted of the movement of the entire population to another site. Accordingly, various land and fluvial communication networks along the coastline were abruptly abandoned during the 8th century. It should be highlighted that some important agglomerates (e.g. Gerace, Stilo, Squillace, and Santa Severina) were consolidated at strategic points from which they could control the main lines of penetration from the sea along the river paths. In most cases, Norman settlements adapted the Byzantine model into a more efficient fortified layout.

To sum up, this brief diachronic analysis of the settlement systems prior to the 18th century earthquakes in southern Calabria shows that the distinct periods of settlement reflected alterations in town-planning strategies in response to demands imposed by the historical situation. The ridgeline settlements of the first historical stages gave way to hillside agglomerations in the second phase. Later on, waterfront settlements were of primary importance until events influenced the return of the population to the most inaccessible ridgelines (*Figure 3.05d*).

At the time of the 1783 earthquake, the Neapolitan milleu differed from that of Calabria[24] economically, culturally, and as regards the type of settlement systems. In fact, the latter was characterized by a sprawl across many small centers, dominated by a rural economy. The majority of these centres affected by the 1783 earthquake were arranged according to the typical medieval layout, namely linear settlement located along dorsal ridgelines or hills, perched on impervious, isolated positions (*urbes*, *castra*, and *castellia*), and, in most cases, connected only to the important Roman axis, *Strada Regia delle Calabrie*, the same route taken south by the Neapolitan observers for reconnaissance after the 1783 earthquake.

[24] In the early 17th century, the domain passed from the Habsburg family to the *Borbone* of Spain. Carlo III of *Borbone* came to power in 1734, followed by Ferdinando IV in 1759. The enlightenment principles from the Neapolitan courts also found a fertile ground in Calabria with leading figures such as Caracciolo, Galanti, Palmieri, Vivenzio, Acton, Tanucci. At this time, a number of adverse events hindered the tranquillity, namely the plague of 1743-1744, the famine of 1763-1764, and the macro-earthquake of 1783.

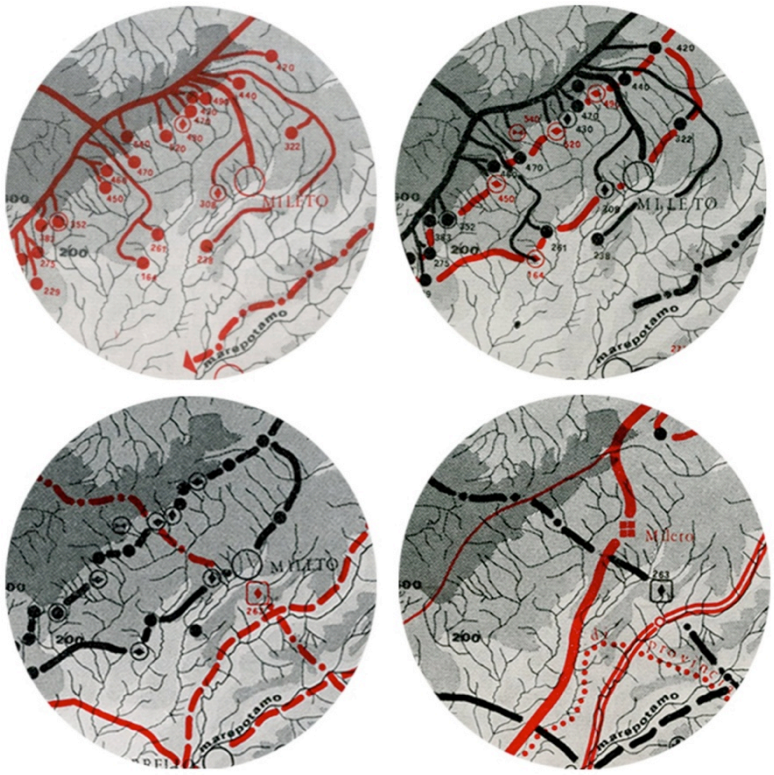


Figure 3.06 – Detail of territorial phases of Mileto from (Cataldi, G. 1974)[25]

Mileto dates back to the first-phase of the comb system. It was later intersected by a road system of the double structure of the second phase, parallel to the primary road but at a lower altitude; next intersected by the transversal anti-peninsular path connecting Tropea and Roccella on the Tyrrhenian and Ionic coasts respectively. Lastly, in the territorial phase of the late 18th century, Mileto's new location was owed to environmental constraints: the town was rebuilt between the route of the old settlement and the peninsular axis of *Regia Strada Postale* proceeding towards Rosarno and Gioia Tauro, which corresponds to the current highway SS 18 (*Figure 3.06*). The cross-forming bidirectional plan was based on a dual ideal symmetry, later discussed in *section 3.5*. It strongly differs from the pre-earthquake settlement pattern.

[25] see footnote 20

3.3 *Borbone* reconstruction works: legislative framework and operational measures

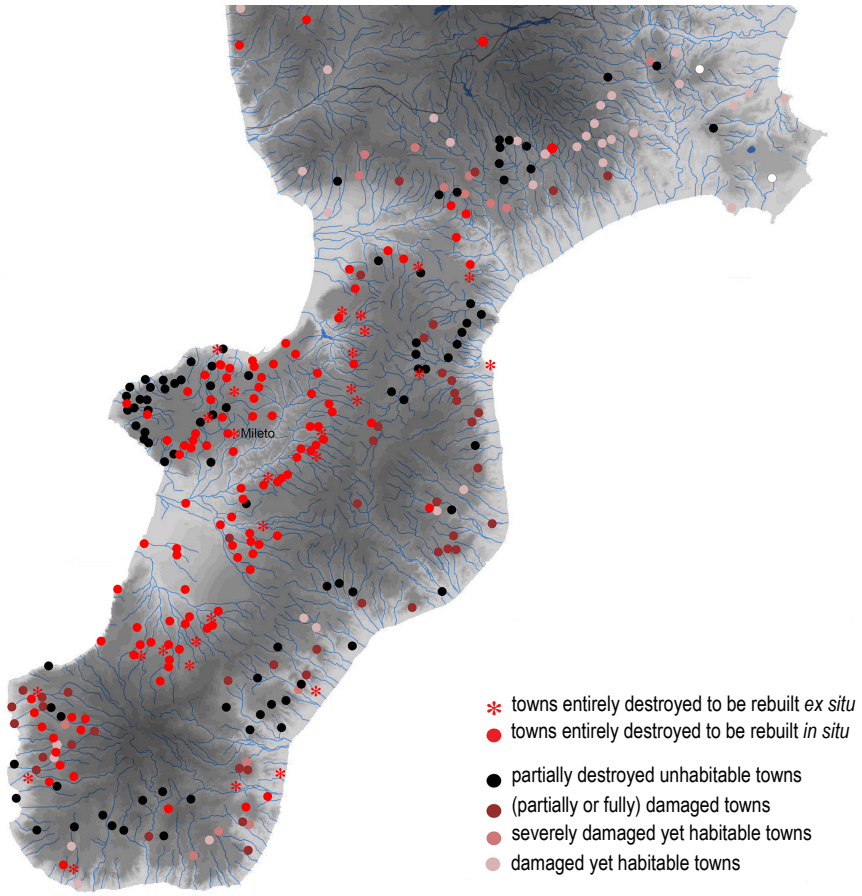
The quake cluster in Calabria and in northeast Sicily – i.e. along the *Siculo-Calabrian Rift Zone* (SCRZ) – lasted three years; it consisted of five principal shocks from 5 February to 1 March 1783 and was followed by strong aftershocks and devastating tsunamis.[26] Human losses and building damage throughout the territory were dramatic (*Figure 3.07*).

This macro-earthquake (7 M_w), much like the 1908 earthquake, embodied a private and collective catastrophe, a presentiment of the end of the world. Notably, despite the cyclical nature and strong impact of previous earthquakes on the morphological and settlement systems,[27] the severity of the 1783 earthquake completely shocked the local population.

Figure 3.08 shows the movement of the successive earthquake epicentres from the Messina Strait to the north-northeast and the extensive reconstruction program implemented over the years that followed.

Less than thirty years before, the earthquake in Lisbon had disrupted religious certainties and interrupted the economic expansion of the capital of a vast colonial empire. The trauma of the Portuguese tragedy echoed throughout Europe – including the Kingdom of Naples, whose peripheral provinces would soon be devastated by the 1783 earthquake. The immediate circulation of information at the *Borbone* court about the catastrophe in Lisbon is evidenced by the correspondence between the Marquis Tanucci and Carlo Guevara (of the dukes of Bovino), currently stored in the Neapolitan Archive.[28] Guevara had been dispatched to Lisbon as delegate to the Ministery Plenipotentiary of the Portuguese court in Lisbon two years earlier. His missive of 2 December 1755 comments: "As regards the losses have been suffered and the impoverished rich people, there is no need to explain in detail, because it is inexplicable."[29]

[26] (Jacques, et al. 2001) (Graziani, L.; Maramai, A.; Tinti, S. 2006)
[27] Seismic peaks of 1638, 1659, and 1743 prepared the 1783 catastrophe (Baratta, M. 1908, 383).
[28] *Archivio Napoletano, Ministero degli Esteri - Portogallo diversi - Fascio 918 (1753-1757)*
[29] Excerpt from the missive, which is collected in BPN: "Delle perdite che si sono fatte, e dè ricchi ridotti in miseria non c'è bisogno di farne dettaglio, perché è inesplicabile."(Cusati, M.L.C. 1974, 115-120)



Figures 3.07 – Damage following the 1783 catastrophes from data published in *Istoria* (1788) (Murru, S. 2016)

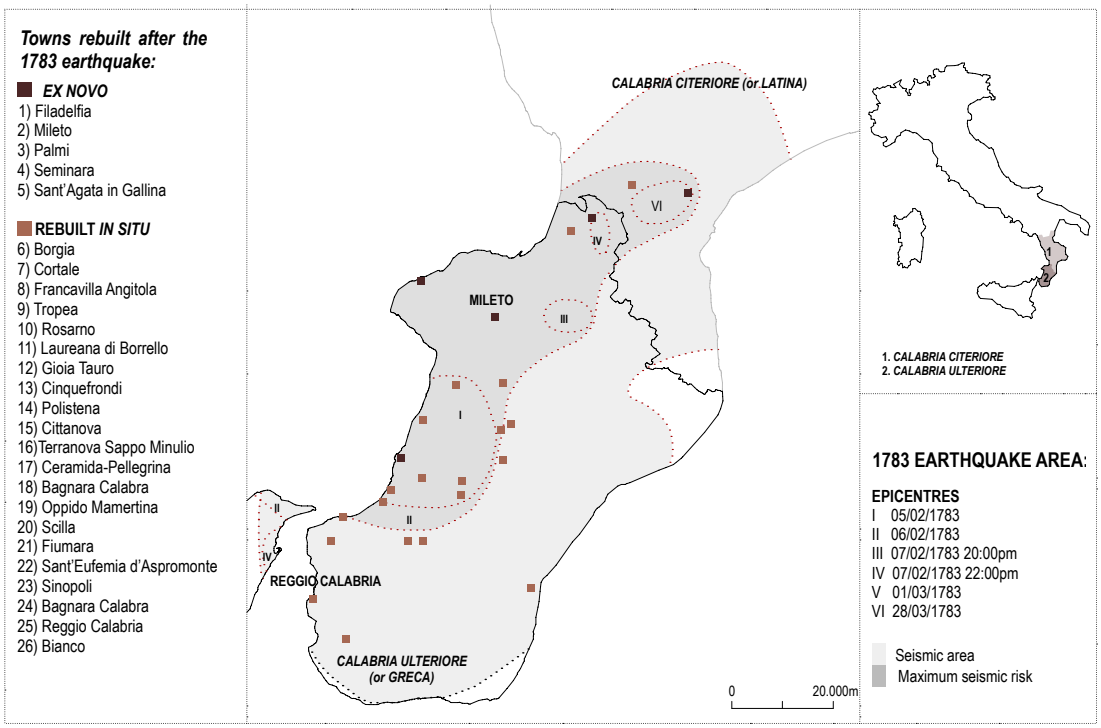


Figure 3.08 – Isoseismal map of Calabria: location of the largest towns rebuilt after the 1783 earthquake, data from (Placanica, A. 1985)(© S. Stellacci)

3.3.1 Urban rebuilding initiatives following the 1783 quake cluster

The relief efforts in the Calabrian provinces were promptly carried out under the chain of command of Carlo III of the *Borbone* Court (r.1759-1788). Due to the size and the morphology of the damaged territory, Monteleone (known today as Vibo Valentia) was selected as the headquarters for its central position, and Pignatelli coordinated all the works. The territory was subdivided into five districts inspected by various engineers directed by official employees; Giovan Battista Mori was responsible for the Reggio district, Claudio Rocchi for Catanzaro, Bernardo Morena for Monteleone, Pietro Galdo for Palmi, and Paolo Scandurra for Gerace.

After the first period of the emergency response, in which the government was involved in the construction of temporary wooden houses, the implementation of infrastructure and the draining of flooded areas, mass emigration was prevented as far as possible, and soldiers were stationed on the shores to turn away outsiders that might bring invasion or contagion. Price controls for materials were attempted, intending to prevent exploitative behaviour. The reconstruction of the towns was begun in March 1784 in compliance with *Borbone* requirements established in *Istruzioni sul metodo da tenersi nella riedificazione dé Paesi diruti della Calabria* (1784),[30] whose 26 articles are summarised in *Tables 3.02a* and *3.02b*.

The long duration of the rebuilding resulted from both the ongoing telluric movements, stretching over few years, from the extreme poverty of Calabrian inhabitants. In some cases, the activities lasted more than a decade, as confirmed, among many chronicles, by Oppido's bishop who complained in a missive to Acton (6 October 1795) about his parishioners encamping in unhealthy temporary wooden houses.[31]The selection of the locations for rebuilding was crucial in the Neapolitan planning. The understanding of the importance of selecting the best town locations was only gained in time. In fact, the initial priority for the engineers was lake draining, and only in the time remaining between those surveys were they dispatched to observe the damaged towns and called to select the new areas.[32]

The basic strategy of the town planning (on-site *vs* off-site reconstruction) is the first important term of comparison between Lisbon and the rebuilt Calabrian towns. Lisbon was settled on its river in ancient times; its dynamic commercial and port zone on the alluvial plain grew in density throughout the Middle Ages and Renaissance. Despite this area's unfavourable soil features and exposure to wind – which had acted to increase the propagation of the fire lasted for six days following the earthquake – the intention to rebuild the city in the same area as before the earthquake prevailed among other alternatives of different localisation and layout.[33]

The scenario was different and much more complex for each damaged Calabrian town. Historically attributed to the military engineers of the *Borbone* Court – Winspeare and La Vega[34] – a variety of different solutions were implemented depending on the location of the original towns and their surrounding conditions, the proximity to cultivated land and the main roads. Of thirty-three heavily damaged towns,[35] only five were built off-

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[30] Instructions on the method to follow in the rebuilding of the towns of Calabria (Aricò, N.; Milella, O. 1984)
[31] (Principe, I. 1976, 156)
[32] Ibid., 314
[33] (Ayres, C. 1910, 33-36) (França, J. A. 1987)
[34] see *Table 3.01a*, art.1. *Ita*:"La situazione delle città, e terre da riedificarsi sarà quella stessa riconosciuta più propria dall'Ing.re D. Antonio Winspeare, e D. Francesco La Vega, ed approvato da S.M.".
[35] Vivenzio indicates thirty-three towns to be rebuilt *ex situ* and one hundred and fifty to be rebuilt *in situ* (Vivenzio, G. 1788, XLVIII), while one hundred and forty seven are indicated in the map *Carta corografica della Calabria Ulteriore* by Padre Eliseo della Concezione as the destroyed towns. Although Reggio was actually rebuilt on-site, it merits inclusion in the discussion of post-1783 new planning of off-site centres due to the extent of the planning for

site *ex novo*: Filadelfia, Mileto, Palmi, Seminara, and Sant'Agata in Gallina (*Figure 3.09*). The other towns (e.g. Laureana di Borello, Scilla, Polistena, and Francavilla Angitola) underwent extensions or partial reconfigurations, and the initiative of the local aristocratic families prevailed on Neapolitan purposes.[36] Small settlements resulted split in different built-up areas, such as occurred in Francavilla Angitola, whose configuration resulted in three zones: the medieval town, a post-1783 residential area with single-cell terraced houses, and a new modern centre.[37]

Table 3.02a – Legislative requirements included in *Istruzioni* (1784), art.1-13

***Istruzioni sul metodo da tenersi nella riedificazione dé Paesi diruti della Calabria*, Chapter 1 (20 March 1784)**

TOPIC	art.	PROVISION
urban planning	1	Urban (or land) location must be in compliance with the indication of Winspeare and La Vega, followed by His Majesty's approval.
	2	Towns (or lands) shall be located in the approved places so that they are far away from the hills, especially if it is necessary to locate them in clay or sandy soils.
road system	3	The roads shall always be exposed to light winds, allowing fresh air to penetrate the urban fabric.
	4	Each town (or village) shall be divided by the main straight streets, not less than 40 palms wide for the town, and 34 for village or lands; these may be up to 50 when required by the inhabitants or the building quality.
	5	The minor roads must be straight, of 30 or 24 palms in width, parallel to the main road, extending for one or two districts (*isola*), and crossing other streets of the same width at right angles. These two articles (art.4,5) shall be taken into account unless the enviromental constraints require another layout.
road pavement	6	All roads must be paved in order to be easly used during the wintertime and in order to be clean and avoid stagnant air.
road system	7	A main plaza in each town (or village) and a market square with a public fountain are required. A second fountain must be located along the *Royal Street* or adjacent to it. In addition to this main square, other smaller squares shall be introduced according to the requirements and extent of each town at sites where some public building, whether religious or secular,
road system/building blocks	8	Religious or secular public buildings and the houses of wealthy people which could be built with certain simple decoration should be located along the main streets.
building blocks	9	All houses shall have a courtyard, without roof or with porch, depending on the taste or budget of the owners. Depending on the type of soil, a plinth and a deep foundation are required. The plinth may rise 5 palms (or slightly more) from the roadway and function as a cellar, with other small windows (saettiere or lumi) in it and the remaining part underground. These cellars are covered by vaults with round arches, whose springers are located above ground, so that these vaults themselves can effectively counteract the ground force.
construction tecniques (ordinary buildings)	10	The houses shall be executed on this plinth or base, which shall be built with a skeleton of massive beams of chestnut or oak, depending on the available species. These vertical posts are placed at the corners and at reasonable distances so as to be connected to transverse beams (which pass over the vertical posts). The skeleton of the platform, as well as of the roof, all of this wooden skeleton embraced of walling so as so any sections is exposed to the weather, and for this reason the wall must be of two and half palms. The walling will be executed with bricks, or small stones, explicitly avoiding employment of smooth stone, which can not be embraced by hand, unless it is first broken by sledgehammer. A slaked Neapolitan lime base mixed with silt or rugged earth (not a clay base) shall be employed. The interior surfaces shall be plastered, as well as the exterior surface with good quality.
	11	In order to avoid the rotting of the beams and lumber to be used inside the construction, these will be seasoned and cut at the proper time. The bark shall be removed, the surface must be charred or tarred, and the beams shall be surrounded by stones or bricks, but not lime mortar.
	12	It is forbidden to erect the houses just with the frames (namely the wooden skeleton), connected by S. Andrew crosses, and filled with lime mortar or gypsum because this type of construction, with the wood being exposed to the air, can easily suffered from the frequent and instant changes in weather; in addition, annoying insects can proliferate due to the extreme warmth which dominates here. This use of frames will be allowed only in the internal partitions, with extreme caution so that the plaster can be applied and completely cover the lumbers. Alternatively, fabric or reed rods, together with the wooden skeleton, should be fully covered by gypsum or lime mortar. This prohibition of full timber-construction is not valid for the barracks to be erected during the earthquake.
	13	*Brest* technique, previously employed in this province, or earth clay bricks mixed with clay, are allowed for the house composed of a single room. A new plinth shall be executed, its wall of two-and-a-half palms reinforced by beams (as stated in art. 9,10,11). As explained by Vitruvius in Book 2, chap. 3, 8, to dry the bricks in the shade for a long time; at the top of the wall, below the roof, a brick part must be executed against water infiltrations.

its reconstruction. The number of re-built towns is counted at thirty-three in the official reports (Baratta, M. 1906, 250-251) (Principe, I. 1976, 154).

[36] (Maretto, P. 1975, 74)

[37] (Principe, I. 1976, 243-249)

Table 3.02b – Legislative requirements included in *Istruzioni* (1784), art.14-26

TOPIC	art.	PROVISION
building geometry	14	The height from the ground floor above the plinth to the rain gutter shall be of 28 palms. In the lowland towns, where the streets may be slightly inclined, the edifices overlooking these streets shall be of the same height. The same rule must be respected in all of the squares.
	15	Single-storey buildings must be on a platform and covered by a roof, with beams well-connected to the transverse beams of the external walls.
	16	Wealthy people may build an additional level above this storey, leaving it to the appointed engineers to prescribe and monitor that the beams provide sufficient strength and are correctly fastened to the lower floor.
	17	The height of the houses up to the rain gutter shall not exceed 38 palms, and shall be uniform for all edifices of this typology. These can be vary in decoration, but must be simple and without any heavy overhanging volumes or stuccos.
construction tecniques (churches)	18	The main churches, as well as those of the episcopal sees and the parishes, are executed according to the requirements of the townsmen. Due to the required volume height, it will not to be possible to erect a stable structure by employing vertical wooden elements; accordingly brick blocks and small stones shall be employed. The roof skeleton bears on the joists at the top of the walls, strongly joined in such a way as to form a frame. The plataform of the churches, the vaults being built in accordance with the above mentioned rule, shall be executed with each beam that act as tie beam, by means of an iron fascia nailed at the top side with a sort of chain where an iron bar is inserted. These beams shall be fixed to other similar to the skeleton of the roof so as to remain embraced within the fabric.Under these plataforms, when the walls that have to bear them, and when somedisdvantagious deformation occurs, following the discretion of the engineers, iron tie beams should be placed to cover the width of the room.
building geometry	19	The dimension of the *isole*, composed of one or multiple building plots between the streets, shall be planned according to the discretion of the engineers and the needs and the habits of the townsmen. The internal layouts of the houses will be planned according to their different demands, but always including a large courtyard, as previously mentioned.
hospital	20	A hospital should be located in one of the peripheral sections of the town, with exposure to the main winds in order to remove exhalations.
graveyard	21	Graveyards should not be located at the churches, but at a specific site at the town boundary, in compliance with the recommendations on wind exposure.
drainage supplies	22	Every town (or village) must be equipped with underground drainage supplies, with the waste water flowing into the valley or open river adjacent to the settlement. The townsmen have to pay taxes for the execution of the drainage, and the pipes of every house have to be connected to the main.
equipment storage areas	23	The equipment for processing olive oil – the main resource of this province – (mills or oil storehouses) is not allowed within the inhabited area. Underground wheat storehouses are prohibited, unless located far away from the dwellings.
urban planning	24	In the site where the new towns will be executed, any existing tree plantations shall be cut; on the sites where the winds are more favourable, the tree plantations must be replaced by other crops that do not impede ventilation.
	25	In town planning the new pattern should be arranged so that future building additions would be possible on lateral sides and by avoiding to fill intermediate spaces, in order to allow the fresh air ventilation.
equipment storage areas	26	What is established as regards the underground oil mills must also be applied to salad, cheese, fishes, and their storerooms.

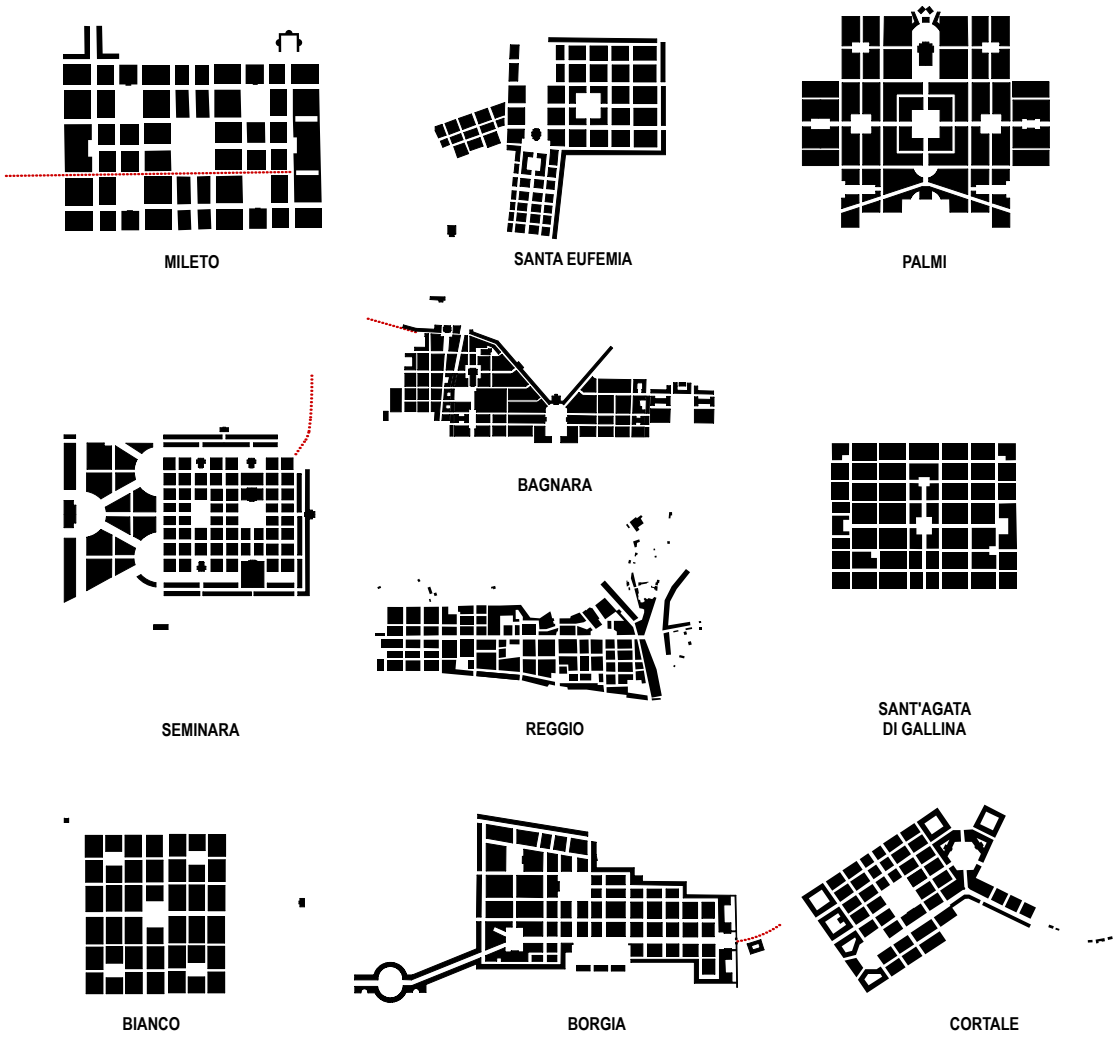

Figure 3.09 – Rebuilt towns included in Vivenzio's treatise:[38] plans and their main axis (in red line) (© S. Stellacci)

In all cases, the urban system differed from the linear arrangement of the pre-existing Calabrian towns. The model of the town, as imposed by the Neapolitan government, was axialized – for the presence of important spatial or architectural elements – and organised around a system of plazas, in which the main square should constitute one tenth of the entire new town.[39] Analogies can be drawn with the Roman influence brought to Portugal in Sanches's treatise to "build wide and straight streets that should end in large squares".[40] However, the squares of downtown Lisbon did not gravitate around pre-existing or new churches; the single monuments were generally absorbed into the building blocks. Conversely, single overlooking buildings – churches with their bell-towers or noble palaces – were intended as complementary points of reference in Calabrian rebuilt tissues.

A set of principles derived from Renaissance model prevailed for complete urban reconstruction in Calabria. The towns were repositioned from morphologically diverse areas – spurs, hills, and ridges – to flat

[38] These ten maps are drawn by the author of this thesis from Vivenzio's treatise re-published by (Rubino, G. E. (ed.) 1992), i.e. plates nos. III (Mileto), IV (Sant'Eufemia di Sinopoli), V (Palmi), VI (Seminara), VII (Bagnara), VIII (Reggio), IX (Sant'Agata di Gallina), X (Bianco), XI (Borgia), XII (Cortale).
[39] From explications of Vivenzio's house published in *Istoria* (1784)(Principe, I. 1976, 367)
[40] "fabricar ruas largas e diretas que se terminem nas grandes praças". (Sanches, A. 1756, 48)

zones, away from peaks and riverbeds.[41] In case of disagreement between the Neapolitan authorities and the local communities over the question of location (off-site or on-site), the opinion of the first group generally prevailed. There were evidently some exceptions, such as Casalnuovo (renamed Cittanova in 1832): after being reconstructed several times over the centuries, this town was rebuilt from the 1783 damage in the same place, despite the unfavourable opinion of the Neapolitan engineers; a regular expansion was executed by embedding new enlightenment-era tissue into the old town.[42] Another exception to the leading principles related to the *ex novo* reconstruction (i.e. flatter and less seismic-prone areas) was Seminara, which was rebuilt to the south-southwest on a nearby upland plain with heavily disaggregated ground of tonalite (igneous plutonic rock). In this case, history proved the Neapolitan engineers right: the new town was rebuilt in a highly seismic-prone zone, as testified by the severe damage sustained in the 1894 and 1908 earthquakes.[43]

In the majority of cases, however, after centuries of closure for defensive reasons, new centres were intentionally re-built in the lowlands (which were considered more salubrious), or in areas with favourable weather exposure (*Istruzioni,* Chapter 1, articles 3, 24, 25) – theories that echoed the recommendations of *De Architectura.*[44] In order to reduce costs, other fundamental conditions of the new towns' locations were proximity to rivers or to the damaged ancient centres and the low economic value of the land.[45]The choice was also influenced by empirical post-earthquake observations, since it was clearly understood that a convergence of different factors, such as the features of the soil (e.g. low homogeneity of Calabrian soils) together with poor building techniques[46] had greatly amplified the earthquakes' effects. As a matter of fact, abrupt variations of seismic wave propagation velocity had occurred, producing a fracture line between the most recent rocks – poorly solid substrates, heterogeneous in nature – and the much older granite.

These rebuilding activities were initiated with great diligence and dedication but had to undergo ups and downs, setbacks, and accelerations. The conflict between the enlightenment culture of the planners (epitomized by Galiani, secretary of the Supreme Court of Commerce)[47] and the local culture – traditionalist and based on baronial large landed estates and on the privileges of clergy and nobles[48]– produced spotty results. Niglio summarizes the failure of this planning strategy: "A mentality only oriented towards control and management of the dominated territory, rather than aimed at rebuilding it to stabilize it socially, culturally and economically".[49] Many scholars have viewed these works as products of the inability of central authorities to deal with emergency situations in the South of Italy, especially by considering the resounding failure of *Cassa Sacra,* which took its

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[41] (Principe, I. 1976, 315)
[42] (Maretto, P. 1975, 81-89)
[43] (Baratta, M. 1908, 165)
[44] Articulating a sort of public health theory, Vitruvius recommends the alignment of the road network according to the directions of the eight main winds, so as to allow fresh air to penetrate the urban fabric as far as possible without being blocked by building facades. This can be interpreted as an ideal radiocentric *forma urbis*, whose convergent axes would be in contrast with the orthogonal layout typical of Roman towns.
[45] *Chapter 4*, *section 4.3.1*
[46] (Valensise, F. 2003, 39)
[47] Galiani's theory assumes the importance of taking advantage of this historic moment for changing the socio-economic structure in Calabria, thwarting the so-called *dead hand*s (*mani morte*) of traditional society. His treatise, *Della Moneta* (1751) promotes the validity of controlled inflation rather than monetary stability (Principe, I. 1976, 136-145) (Rubino, G. E. (ed.) 1992, 16-17).
[48] Some of the most important Calabrian noble families, owning large plots of land or exercising influence superior to the provincial authority itself on large urban and rural areas, are identified by Galiani (Ruffo, Gambacorta, Serra, and Caraffa) and by Cataldi (Spinelli, Pignatelli, Grimaldi, Caracciolo, and Milano) (Cataldi, G. 1974, 136).
[49] "Dominava infatti una mentalità finalizzata solo a controllare ed a gestire il territorio, anziché a ricostruirlo per stabilizzarlo socialmente, culturalmente ed economicamente."(Niglio, O. 2011, 48)

legal basis from the *Istruzioni*.[50]

Established in Catanzaro in June 1784 and lasting for twelve years, this governmental body was tasked with confiscating ecclesiastic properties and economic revenues of the churches and convents of Calabria in order to finance the land reclamation, the reconstruction of the towns destroyed by the earthquake, as well to boost the economy of the hinterland.[51] Created with the goal of wealth redistribution and the rise of a new class of small owners, in practice it actually favoured the bourgeois and noble classes, already the owners of property. This favoritism can be explained by the fact that *Cassa Sacra* could borrow money at a maximum interest rate of 4%, to be granted to those who would ask for the reconstruction of their home with a degressive rate of 6% with the debt to be paid off over twenty-eight years.[52] The money was distribuited in three tranches (at the beginning, middle, and end of the works). *Cassa Sacra* had also the faculty of selling or renting the property belonging to the suppressed monasteries; unsold properties were granted in *emphyteusis* with the obligation to pay an annual fee. The opportunity to purchase the ecclesiastical properties outright favoured the wealthy classes. As defiined in Chapter IX, art.4 of Borbone legislative body,[53] if citizens could not afford to borrow and repay money, *Cassa Sacra* had to build the houses (single-room, e.g. about 2.3-2.6 square meters per person)[54] at its own expense for poor people. Materials, such as tiles and windows, from the old houses were reemployed to reduce houses costs.

The Neapolitan reformists did not fully understand that these loans would have been out of reach of the majority of the population and they also underestimated the role of social price controls played by the ecclesiastical system prior to the establishment of *Cassa Sacra*, which granted loans to richer families – *galantuomin*i or *massari* – and only to weaker social classes depending on their capacity to pay back.

[50] *Cassa Sacra*, *Segreteria pagana*, b.66, fasc.1062, cc.3-3v
[51] (Grimaldi, A. 1863) (Principe, I. 1976, 314) (Valensise, F. 2003, 49-55)
[52] Principe refers to the houses rebuilt in Pentidattilo, a small village near Reggio Calabria (Principe, I. 1976, 314).
[53] *Istruzioni da eseguirsi dall'ispettori, ed ingegneri direttori, per aversi il magior commodo, e provedersi ai totali bisogni della Calabria Ulteriore*, published by (Aricò, N.; Milella, O. 1984)
[54] (Placanica, A. 1979)

3.3.2 Vivenzio's casa baraccata: on the feasibility of architectural and technical solutions

Traditional anti-seismic structures of the south of Italy (in Calabria and Sicily) are commonly named *case baraccate* (*barracks*). This term, originally associated with the extreme poverty of their inhabitants and the precariousness of their living conditions, was redeemed primarily by Pesso in 1876[55] and, some years later, by those technicians appointed to survey the leveled Reggio Calabria and Messina's buildings in 1908.[56]

A discussion of the Calabrian *casa baraccata* requires some preliminary clarifications. This construction type includes some variants, different in terms of use, proportion, and connection of the key elements (masonry blocks and lumbers). Over its prolonged use in time, since this technique cannot be associated to a particular social status of building owner or to a single building typology (they can be either isolated palaces or row houses (i.e. with monocellular fronts) *casa baraccata* can be viewed as the result of a long-standing effort to avoid severe damage mechanisms under seismic forces.

First of all, there are two very different types generally referred to as *barracks*. The first category, outside the scope of this study, refers to those one-storey structures made of wooden planks, often granted free of charge and temporarily, to be used while waiting for the construction of new dwellings. Well-known examples of temporary relief houses are depicted in a view of Mileto, framed on the left by leafy branches behind which the old settlement can be seen[57] (*Figure 3.10*).



Figure 3.10 – Mileto: new barracks and the old settlement, Schiantarelli's etched plate (Sarconi, M. 1784, plate no.VIII)

The second category concerns non-temporary domestic buildings (isolated houses or integrated in blocks), where the external masonry, so-called *parete intelaiata*, is reinforced by a single or double timber framework: a set of horizontal (sometimes diagonal) wooden elements braces massive vertical wooden posts.

In the kingdom's legislative body, the first indication of an earthquake-proof house is found in the *Istoria*

[55] (Pesso, L. 1876)
[56] (Fiandaca, O.; Lione, R. (eds.) 2009)
[57] see footnote 94

de' fenomeni del tremoto avvenuto nelle Calabrie e nel Valdemone nell'anno 1783.[58] The *Istoria* was credited to Sarconi, the secretary of the *Accademia di Scienze e Belle lettere* of Naples, and was published at the end of 1784, when the seismic crisis was still underway.[59] The guidelines included in this treatise became law in March 1784, composed in 26 articles (*Tables 3.02a*, *3.02b*), and remained in effect until 1854.

The atlas consists of 68 plates drawn by Schiantarelli (1746- 1802/05), Stile, and Rulli,[60] and engraved by Zaballi (1738- 1785) during the exploratory campaign organised by the Neapolitan Academy and led by Sarconi just two months after the first shock, ending in Messina in September of the same year. It's no accident that the *Istoria*'s epigraph refers to direct experience: "Haec ego non legi, non audivi, sed oculis meis vidi".[61] Being the first official post-earthquake mission organised by a scientific institute in Italy, this mission was seminal. It should be pointed out that Sarconi unduly appropriated the authorship of this first edition of the *Istoria* (mentioning himself and Padre Eliseo della Concezione as authors) – so much so that he was remembered with the nickname of *Don Ciccio Fenomeno* ("The Phenominal Mr Ciccio") for having supposedly accomplished so much on his own.[62] The *Istoria* is today understood as a collective work, with Ferrarese as one of the most important officials, "indifferent to personal ambition by training, [he is] fully satisfied with the correct application of the rules".[63]

Regardless of the *Istoria*'s paternity, what matters is to understand its technical recommendations to ensure adequate safety in the new building constructions and its direct impact on practise throughout the 18th and 19th centuries. A second edition of the *Istoria* published in 1788 by Vivenzio,[64] a royal physician and brother of the scholar and tax lawyer of the *Regia Camera della Sommaria*. Although its text was more extensive, it lacked four drawings and their explanations which are present in the first edition. Three of these drawings show the model of an anti-seismic house (i.e. elevation, section, and plan of a building, *Figure 3.12*, bottom). In these plates Ferrarese is credited as the *inventore* of *Case formate di legno* (Houses composed of wood) and Cattaneo as the engraver. The fourth drawing is a map of *Calabria Ultra*, corrected by La Vega on the basis of Rizzi-Zannoni's map of a few years before.

As emphasized by Tobriner,[65] the structural characteristics of Vivenzio's house are in accordance with modern concepts of anti-seismic engineering science: axial symmetry,[66] limitation of height, regularity of openings, reinforcement of masonry wall by a timber skeleton, as well as lack of heavy overhanging elements. Despite the

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[58] *Istoria dè Fenomeni del Tremoto avvenuto nelle Calabrie, e nel Valdemone nell'anno 1783 posta in luce dalla Reale Accademia delle* Scienze, *e delle Belle Lettere di Napoli*, which included the appendix *Atlante iconografico* (*Account of the Effects of the Earthquake in Calabria and in Valdemone in 1783*) (Sarconi, M. 1784). *Istoria* was reprinted as anastatic copy by Zinzi in 1987, while the plates were published in 1990 (Zinzi, E. (ed.) 1990).

[59] According to Placanica, Vivenzio's volumes can be viewed as an instrument for the government defence the criticism to the *Borbone* planners (Placanica, A. 1985, 27).

[60] (Sarconi, M. 1784, xiii)

[61] "I have not read, not heard of it, but with my eyes I have seen these things." (Petrarca, *Epistolarium* no. 5, Book no. 5).

[62] *Ciccio* is Francesco's nickname, here indicated ironically since Francesco is very common in Italy. Principe quotes the nickname of *Don Ciccio Fenomeno* (Principe, I. 1976, 36) (Rubino, G. E. (ed.) 1992, 21).

[63] "*alieno per formazione a velleità personalistiche, appare pienamente appagato dalla corretta applicazione dei canoni*." (Rubino, G. E. (ed.) 1992, 24)

[64] Giovanni Vivenzio, *Istoria de' tremuoti avvenuti nella provincia di Calabria Ulteriore, e nella citta di Messina nell' anno 1783, e di quanto nelle Calabrie fu fatto per lo suo risorgimento fino al 1787, preceduta da una teoria, ed istoria generale de' tremuoti* (two volumes, of which the first with 427 and the second with 144 pages) and the *Atlante* (21 plates, ten of which are the map of the new towns, eight of the lakes, two technical instruments, and a map (Vivenzio, G. 1788).

[65] (Tobriner, S. 1983) (AA.VV. 2010)

[66] Dissymmetry arising from different disposition of interior walls (e.g. on the lateral volumes) can however produce torsional effects (Tavares, A.; D'Ayala, D.; Costa, A.; Varum, H. 2013, 17).

virtues of these key principles, this model is limited by its low feasibility. Alternatively, it can be viewed as an ideal model of the principles to be followed by Calabrian builders who would adapt (or simplify) it according to technical and economic constraints. For these reasons, together with the low (and thus expensive) supply of wood, the existing *case baraccate* embodied a system very different to their anti-seismic model. Their model is composed of three English-style blocks with the middle being an *avant-corp*, which is embellished by an ashlar base and by four giant Ionic columns, surmounted by a neoclassic tympanum. Ingenuously (as a sort of socialist utopia?), the central block is interconnected to the lateral volumes: the central edifice – the house for a "rich Townsman" – extends for 60 palms (approximately 16 m), while the two lateral blocks – on one side, the peasant's house, and, on the other side, their warehouse – each extend for 40 palms (approximately 10 m).

The regularity and the subdivision into three volumes are logical: the first prevents torsion and stress accumulation, while the lateral blocks buttress the central one, preventing out-of-plane failure of the facade onto the street in case of collapse of the main volume during an earthquake.[67] What it is unclear is how such oversized blocks could have been executed in the newly rebuilt towns, which did not exceed 10,000 inhabitants. It was also inconsistent with the regular urban neighbourhoods as drawn in the map for the new towns (*Figure 3.09*). As better seen in *section 3.5*, this type of building, based on three symmetrical connected volumes, was never executed in this territory, where, instead, a simple building configuration prevails.

The proportions of these cubic volumes, the horizontal cornice that unifies these edifices, as well as the layout of openings, recall Morris's *Cube*[68] (*Figure 3.11*, top). The main difference between Morris and the Calabrian model arises from Ferrarese's interest in the seismic-resistant construction system, although it is not easily executable. Tobriner outspokenly defines it as "a nightmare for both carpenters and masons".[69]

The skeleton of these three volumes is composed of a dense grid of vertical oak posts; some of these, stuck in the ground, are continous from the foundation to the roof. The peripheral walls of each lateral block (peasant's house) are simpler than those of the central volume since the group of four vertical posts at each corner of the central edifice is replaced by a single post. In the main volume, lacings of X-braces frame each opening. Details for walls of public buildings (*grandi muraglie de´ pubblici Edificj*), timber truss, and lightning rod are depicted in plate no. III (*Figure 3.12*, bottom left). In contrast with the majority of heavy ceramic roofs executed in Calabria (and in the whole south of Italy) that failed disastrously in 1783, the proposed system includes timber truss covered by slate shingles or baked clay. In addition, in order to connect and allow the building to act as a unit, the vertical posts (*A* in *Figure 3.12*) are connected to the bottom chord by means of their carvings. The multi-leaf reinforced masonry wall to be executed in public buildings can be viewed as a box composed of: (i) a ring of double beams – connected at the bottom and over the entire length by dovetail joints (*F* in *Figure 3.12*); (ii) in the middle infill materials, which can be dressed stones (with lead cramps) or rubble stones in the case of less expensive buildings. Similarly to the central volume (i.e. house of the "rich Townsman"), the external wall for public building is reinforced at each corner by a group of four vertical posts (*A*, *B*, *C*, *D* in *Figure 3.12*).

The influence of the wooden anti-seismic house may have arisen from Milizia's theories contained in *Principi di architettura civile* (1781), characterized by these key technical aspects: (i) the interlocking of each component in order to provide a single volume; (ii) stone foundation, which should be larger than the ground floor area; (iii) slight inclination of the ground in order to ensure storm-water run-off; (iv) building height, which should be

[67] (Tobriner, S. 1983, 134) (Tobriner, S. 1997, 111)
[68] (Morris, R. 1734, 138)
[69] (AA.VV. 2010, 29)

lesser or equal to its width. A difference between these two treatises can be observed regarding the connection between the foundation and the ground. Driving the wooden stakes into the ground,[70] followed by directly laying the pavement, is not recommended by Milizia, while the solution proposed by Vivenzio includes the driving of vertical timber posts on a footing of the building. The height of this plinth should be of three palms (0.80 m); this elevation should provide the ventilation necessary to control moisture (*Figure 3.11*, see cross section).

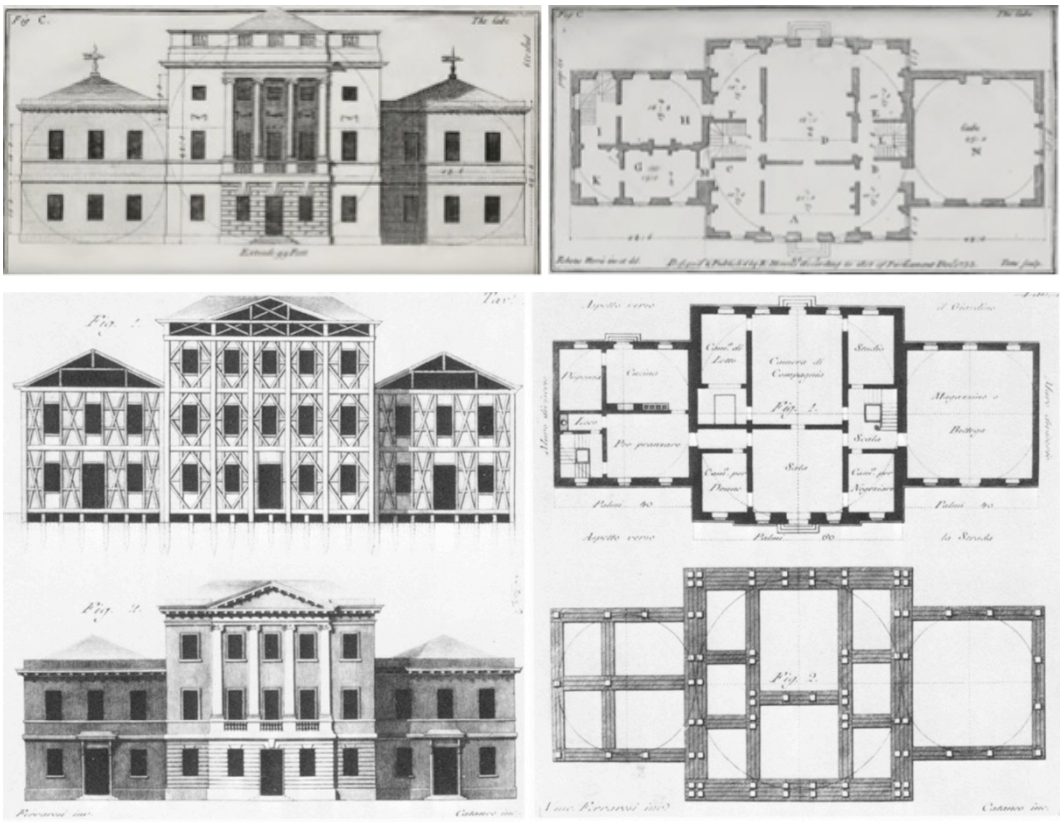

Figure 3.11 – The *Cube* (Morris, R. 1734, 138) *vs* Vivenzio's house, 1783 (Principe, I. 1976, 367, plates no. I, II)

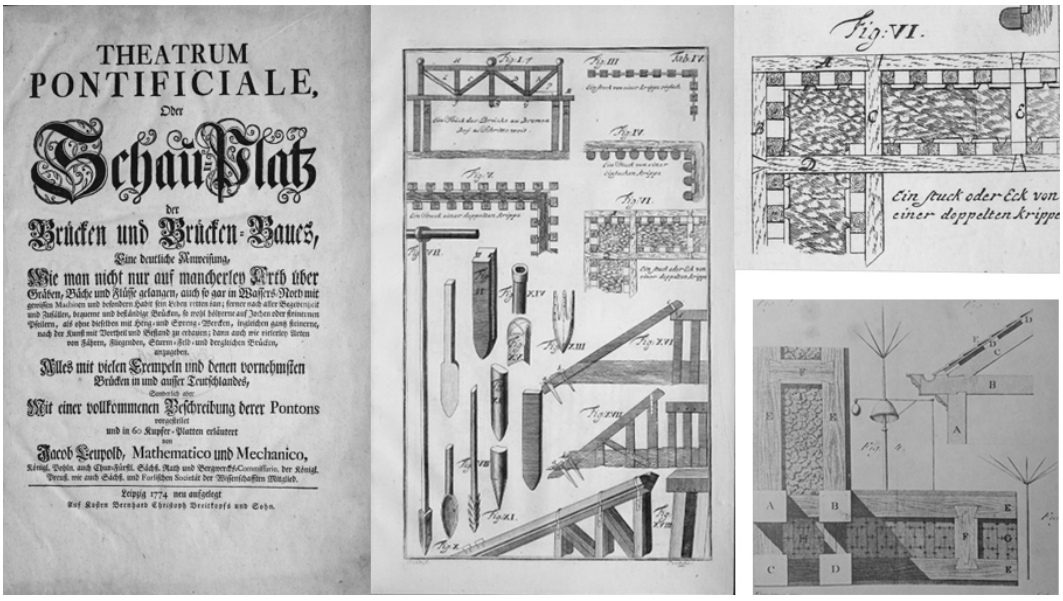

Figure 3.12 – Reinforced masonry wall: Leupold's *Teatrum pontificale* (Leupold, J. 1774, 183) *vs* Vivenzio's

[70] The execution of wooden foundation piles is recommended by Vitruvius as an effective solution for the consolidation of the loose soil (*D.a.*, II, 9, 11; III, 4, 2).

earthquake-resistant public house, 1783 (Principe, I. 1976, plate no. III)

Analogies exist between plate no. III and the drawing published in *Teatrum pontificale* (1726) by Leupold, one of the first to study the deformative state in the trusses.[71] Foreign influences on this construction type underpin all Neapolitan proposals, for example by Vivenzio recalling Monceau's theories.[72]

Plenty of evidence of timber frame walls exists in the Campania region;[73] these are known as *beneventana* walls since they were employed for the first time in the papal Benevento, dating back to the post-1627 earthquake (whose epicentre was in the Apulia region, 6.7 M_w). It consists of a timber framework fixed to a masonry base and filled with lightweight materials, e.g. canes and wood, bonded with mortar and plastered.



Figure 3.13 – 17th century timber-framed building in L'Aquila under demolition, archival photo published by (Nobile, M.R.; Scibilia, F. (ed.) 2016, 148)

An archival photo, *Figure 3.13*, captures the moment when a 17th century timber-framed building in front of the Basilica di San Bernardino was demolished. Except for steeply sloping scarp walls at the ground floor, many visible analogies with the Calabrian houses can be found: low height, regularity and alignment of the openings, and above all, the timber skeleton with diagonal frames beyond the thick masonry wall at the second floor.

[71] (Ruggieri, N. 2011, 10)
[72] *De l'exploitation des bois, ou moyen de tier une parti avantageux des taillis, demi-futaies ed hautes- futaies, et d'en faire une juste estimation: avec la description des arts qui se pratiquent dans les forêts, Parigi* (1764).
[73] Ischia and the internal areas of Sannio, Irpinia in particular.

3.4 On-site post-seismic observations and building practice in the south of Italy prior to the 1783 earthquake

The analysis of the building practice in Calabria during the 16th and 17th centuries might shed light on the controversial question of the influence of *Pombalino* technique on *Borbone* reconstruction. Portuguese influence on the Calabrian anti-seismic system is now generally accepted, though still contested by some scholars.[74]

As previously seen in the *beneventana system*, traditional timber-framed houses existed for many centuries in southern Italy long before Sarconi's survey campaign, when concern about earthquakes was already one of the influential factors in the choice and diffusion of local construction systems, together with economic feasibility (cost and availability of materials), the technical skills available, and the needs of those who would occupy the buildings. However, the presence of vernacular timber-framed buildings does not disprove the influence of the Portuguese reconstruction phases on the *Borbone* governmental model, especially considering the wide cultural exchange in this epoch. At the same time, simplistic interpretations of direct influences between *Pombalino* and *Borbone* episodes should be avoided, since, as suggested by França[75] it should not be forgotten that the urban planning and technical breakthroughs introduced during Lisbon's reconstruction did not have the same echo in Europe as the 1755 earthquake and the earthquake damage itself.

In addition to the problem of understanding whether the Calabrian vernacular timber-framed dwellings were viewed as proto-antiseismic structures,[76] the second question concerns the characteristics of these constructions pre- and post-1783.[77]

As referenced by Vincenzo Magnati,[78] evidence of timber-framed construction dates back to the 14th century (Lazio region). This is a wooden construction in Rieti, in the cloister of the convent of the Dominican friars, where Pope Boniface VIII hurriedly went to take refuge after the earthquake shocks of 1 December 1298. Timber structures within the private area close to the main building, called *tabernacles* or *barracks,* whose specific function was anti-seismic shelter, would have been very common: "Since this country [Calabria] was always subject to earthquakes, almost all Barons keep prepared in their palaces one of these shacks to use when there is the first sign of a shock (…)".[79] Being a single edifice (not a temporary structure or outbuilding of a palace), the Noble Palace in Filogaso[80] is another interesting example cited in Hamilton's chronicle. Although not identified in

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[74] While Barucci (Barucci, C. 1990, 28) and many researchers support the idea of a Portuguese influence on Calabrian technique, Tobriner points out: "However, since this system [*Pombalino*] had not been published, and the researchers working in 1783 nowhere alluded to it, there is little doubt that the Calabrian solutions were worked out independent". (Tobriner, S. 1997, 111)

[75] (França, J. A. 1987, 154-160)

[76] "The question is, how much did local vernacular structures influence the formation of the government's system?" (Tobriner, S. 1983, 132, footnote 6)

[77] Various factors have thwarted the permanence of the Calabrian traditional timber framed system over the centuries, amongst which probably the *historical mobility* of the settlements is the most relevant (*section 3.2.2*), together with frequent post-earthquake damage of 20th century followed by building demolitions and reconstructions. In addition to these difficulties, the general lack of interest for safeguarding local humble (or ordinary) buildings should also be noted – a striking attitude when compared to the Italian legislative framework and current practice.

[78] (Magnati, V. 1688)

[79] "Siccome questo paese [la Calabria] fu sempre soggetto ai terremoti, quasi tutti i Baroni tengono preparata presso i loro palazzi una di queste baracche per ricoverarvisi al primo segno di una scossa (...)". (Hamilton W. 1783, 32)

[80] Following the 1659 earthquake, Filogaso was rebuilt from scratch *ex situ* and then overwhelmed by the 1783 earthquake.

any existing building in this city today, it is well-known due to being noted by Vivenzio as one of the few unscathed constructions in the apocalyptic scenario that followed the 1638 earthquake: "(…) in Filogaso, the ancient Palace of the Count of Nocera, past owner of the site who today is the Lord Prince of Scilla, which had been constructed in the past century in wood and covered only with wall, remained unscathed in the whole interior, while the rest of the Town was levelled". [81]

In the old Mileto, the attentive Neapolitan observers refer to another edifice close to the abbey, used as refuge during the frequent earthquakes. Being a timber-framed construction, it remained unscathed during the seismic shock on 5 February 1783, although it was later levelled due to another shock waves on 28 March 1783. Once reduced to rubble, the walling disclosed its features, the internal massive timbers to which the outer surface – wattle and daub and a thin layer of plaster – was still attached.[82] According to the account of the officials reported in the *Istoria*, the notable points are twofold: the timber skeleton placed as wall reinforcement to brace all components, and the large foundation beneath an empty underground space – a sort of shaft – which did not suffer any seismic damage "a sentimento di alcuni savj"(due to the knowledge of some sages).

The scraps of this edifice sadly recall another massive building damaged in the same territory at Triparni (a few miles north of Mileto) in the wake of the 1905 earthquake, as mentioned by Baratta – a geographer regarded as a founder of modern seismology: "in the midst of such fallen ruins some internal walls can be seen with a primitive 'baraccatura'".

Therefore, knowledge of previous Calabrian building practice can be inferred by official reports written by engineers from the *Borbone* Court in the late of 18th century, and from the Italian government in the first decade of the 20th century. On-site inspections were carried out in the aftermath of the respective earthquakes that occurred in this region with the aim to avoid future loss of life by firstly ascertaining the reasons for the building failures.

Prior to the 1783 earthquake, monuments and palaces were generally built in stone or rubble masonry, obviously with more accuracy and better materials than the ordinary domestic buildings, although some of these displayed non-compliance with the basic technical rules (*regola d'arte*).[83] For example, some construction faults were observed in the bell tower of the cathedral in Mileto (old town) on 6 June 1777: in order to reduce costs the builders had left empty spaces in the wall that should have been filled by stone and lime mortar.[84]

Humble dwellings consisted of a single compartment, whose walls were made of timber frame filled by *terraloto*, a raw earth employed to overcome the lack of lime.[85] Two- or three-storey domestic buildings were executed with unreinforced walling made with rubble stones (also with large river stones) or with compacted sun-dried bricks, prepared with a mix of clay and straw or rubble gneiss stones (*brest*).[86, 87] These walls were thus very

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[81] From explications of Vivenzio's house (Principe, I. 1976, 368):"(...) in Filogaso l'antico Palazzo del Conte di Nocera Possessore un tempo del luogo, del quale oggi n'é l'utille Signore il Principe di Scilla, ch'era stato costrutto nel passato secolo di legno, e rivestito solamente di fabbrica, si rimase tutto l'interiore illeso, nel mentre che il resto del Paese fu uguagliato al suolo".

[82] "These [walls] were composed with such ingenuity that, the inner parts were fully interlocked with lumbers, placed so as that these were covered in the vertical corners by regular layers of canes and a thin exterior fabric." *Ita*: "Questi [muri] erano formati con industria tale che, che l'interno viscere era tutto intersecato di legni, congegnati in modo, che ad angoli verticali tenevano in tutela gli strati regolari delle sovrapposte canne, e la sottile fabbrica esteriore." (Sarconi, M. 1784, 44)

[83] See *Chapter 2*, *section 2.2.3*, footnote 88.

[84] (AA.VV. 1999, 59)

[85] *Terraloto* constructions are referenced in the *Istoria* (Sarconi, M. 1784, 52).

[86] The adobe is denominated *mattunazzu*, *bresta*, or *bisola* according to different geographic locations in Calabria. The first refers to Crati's valley, the second to the central south area, either on the Ionic coast (Siderno), or along

similar to the *adobe* technique and were reinforced in the openings or at the corner by dressed stones. The horizontal structures were loaded by walls, which included indentations in the inner face for holding the wooden joists and rafters. While this construction system has been largely employed in humble houses either in rural or urban areas,[88] the hypothesis that the earth and mud structures were used only by poor people must be discarded, since plenty of evidence of this technique is found in row buildings, isolated rural houses (*Figure 3.14*), colonial houses, and other ancient walls. Brick and empty terracotta jars are cited as other traditional materials in some of many patent applications for anti-seismic building systems (e.g. 24 June 1909 by Frezza).[89]



Figure 3.14 – An humble construction in *brest* in the outskirts of Mileto ((© S. Stellacci)

In accordance with the negative judgement expressed in Vivenzio's treatise,[90] many chroniclers state that the Calabrian construction techniques were unsafe and extremely poor due to absence of any anti-seismic devices, the lack of mortars, and the types of materials, with some exceptions.[91] The components were commonly held together by earthy mortar or by clayey earth and cobblestones. In the wake of frequent post-seismic reconstructions, on-site surveys show that the structural vulnerability of the building stock owes to its poor techniques or on its layout, in particular due to asymmetric layout, presence of heavy overhangs and protruding roofs. Rough stone walls were made with very bad mortar that was weakly amalgamated, while the roofs were constructed with trusses and often with simple struts almost always without bottom fascia.

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the Tyrrenian coast (Gioia Tauro, Alto Mesima, headland of Poro, and Vibonese), whereas *bisola* refers to the Messina Strait (Cavalcanti, O.; Chimirri, R. 1999).

[87] It is fairly similar to the Portuguese construction technique called *taipa*, which consists of parallelepipeds made of clay using wooden molds and dried in the sun (Oliveira, E.V.; Galhano, F.; Pereira, B. 1988, 316-317).

[88] Its use was encountered in the historical hub of Catanzaro (Valensise, F. 2003, 38).

[89] ACS, Min. AIC, UCB, n.103254 *apud* (Barucci, C. 1990)

[90] From explications of Vivenzio's house published in *Istoria* (1784) (Principe, I. 1976, 368).

[91] That the Norman castle in Monteleone remained unscathed was attributed to the excellent quality of the lime used (Sarconi, M. 1784, 27-29).

3.5 Mileto from the original project to the implementation plan

Prior to the 1783 earthquake, the city was a typical *castrum* (known as *Castrum Melitense*), a village perched on three hilltops, each of these distinguished by its own religious architecture,[92] along a typical narrow and elongated spindle-shaped pattern, with a building expansion eastward. The accesses to this *castrum* to the southern sides, including the Roman *Via Popilia*, were controlled by a fortification as shown by Pacichelli's etching from his visit to the episcopal seat following the earthquake of 1659.[93, 94]

3.5.1 The new Mileto, arising from historical legacies and reconstruction initiatives

Whereas the medieval settlement was situated on the cliff overlooking the plain (*Figure 3.15*), ancient Mileto had in fact been founded on the alluvial plain. In 1783, in spite of the limited damage to the medieval settlement – just 50 casualties out of 1,689 habitants, with 141 houses destroyed,[95] the *Borbone* military engineers chose a site two kilometers to the west, rebuilding Mileto in the place where it had first been settled.

Some insights on the transition between the old and the new settlement can be established by analysing parish records.[96] In fact, reference is made in the *Liber defunctorum* to a burial in the "Eccl (s) dir. S (ancti) Michaelis Archangels" (from 1070 the Benedictine abbey in the old town from the 12th century) on 6 February 1784, while on 1 November of the same year, the first burial took place in the "Eccl (es) to S (ancta) and Mariae de Catholica noviter erecta" (the newly-built cathedral). The transfer to the new city was concluded two years after the macro-earthquake, as testified by the baptism of Eleonora Rosa Maria Zangara on 22 February 1785 in the new "Civitate in Eccl (es) at S (ancti) Michaelis Arch(ang)eli ".

The 18th century settlement was built on land owned by a bishop and on a large property of the dukes of the *Infantado,* called *La Villa,*[97] identified in Vivenzio's plotboard by its triangular perimeter (*ABC* in *Figure 3.16*); there was also a pre-existing *Baracca Baronale (Baronial Barrack)*. The town, extended for 360 X 550 m, was erected away from the old center, on a high plateau under a ridgeline. This site was chosen for the presence of the *Strada Regia* (*Royal Road*, identified by *L* in *Figure 3.16*), the crucial road axis of this city, alongside which the double square would be situated.[98]

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[92] A previous earthquake in 1638 had damaged some monuments in the old settlement of Mileto (Occhiato, G. 2002). Few ruins of the medieval settlement were still partially visible located in the southeast of the new Mileto, including the findings of the Benedictine Abbey of SS. Trinity (1063) (*C* in *Figure 3.15*).

[93] (AA.VV. 1982, 29)

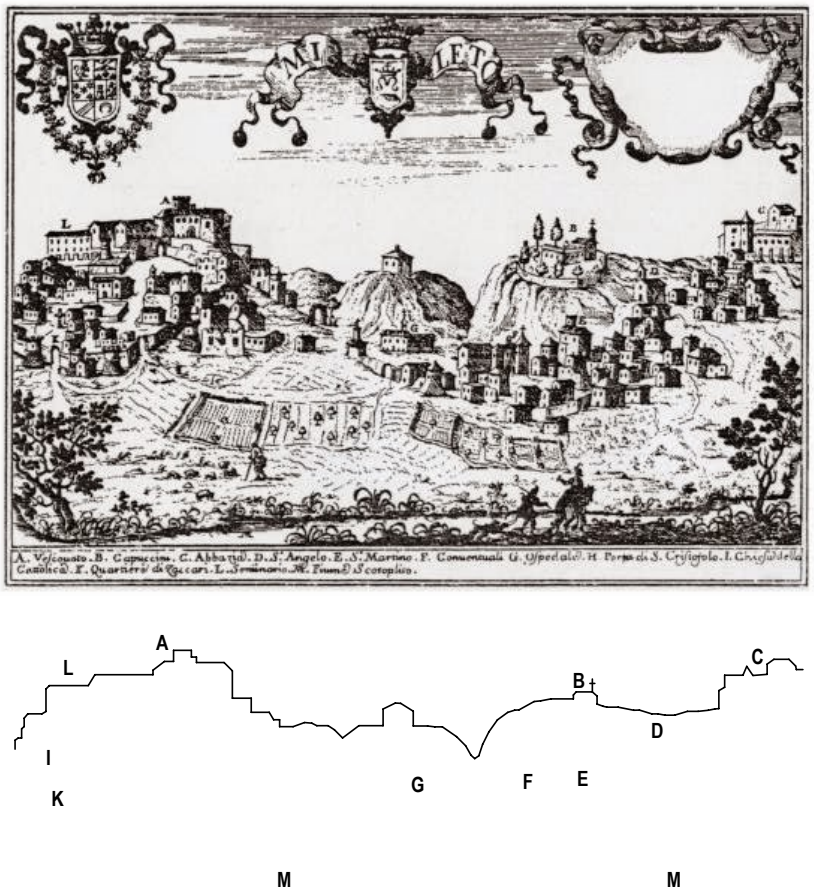
[94] Principe points out that the bishop's seat is represented in the atlas of the *Istoria* (*Figure 3.09*) in the opposite position to that depicted by Pacichelli (*L* in *Figure 3.15*) (Principe, I. 1976, 390)

[95] (Taccone-Gallucci 1881, 31-32) (Baratta, M. 1908, 183) (Principe, I. 1976, 250)

[96] *Liber baptizatorum* (ASDM 1764/1801) and *Liber defunctorum* (ASDM 1764/1801) are respectively the registers of baptisms and of deceased persons (AA.VV. 1999, 59).

[97] Founded in 1768, it was surrounded by fruit trees and roads, among which *Via della Posta* corresponded to *Strada Regia* (the current *Corso Umberto I*) (Taccone-Gallucci 1881, 34). The presence of *La Villa* is referred in the missive of 24 April 1783 written by Winspeare and La Vega to Pignatelli and published by (Principe, I. 1976, 343-344).

[98] Apart from the *Strada Regia*, the roads into the town are: one leading to the small settlement of Calabrò, two to the old town destroyed by the 1783 earthquake, and on the opposite side one towards a stone quarry. In the upper-left corner there is a building expansion (*Borgo ameno*), perhaps already partly built at the time.



A. *bishop's seat, cathedral, and castle*; **B.** *convent of capuchins*; **C.** *abbey of holy trinity*; **D.** *church of Saint Angel*; **E.** *church of Saint Martin*; **F.** *convent of Saint Francis*; **G.** *hospital*; **H.** *Saint Sebastian gate;* **I.** *church of Cattolica*; **K.** *neighborhood of Zaccari*; **L.** *seminary*; **M.** *Scotopilo river known as* warm water

Figure 3.15 – View of *Castrum Melitense*, print of Muzio's etching (1703), adapted from (Pacichelli, G.B. 1703)

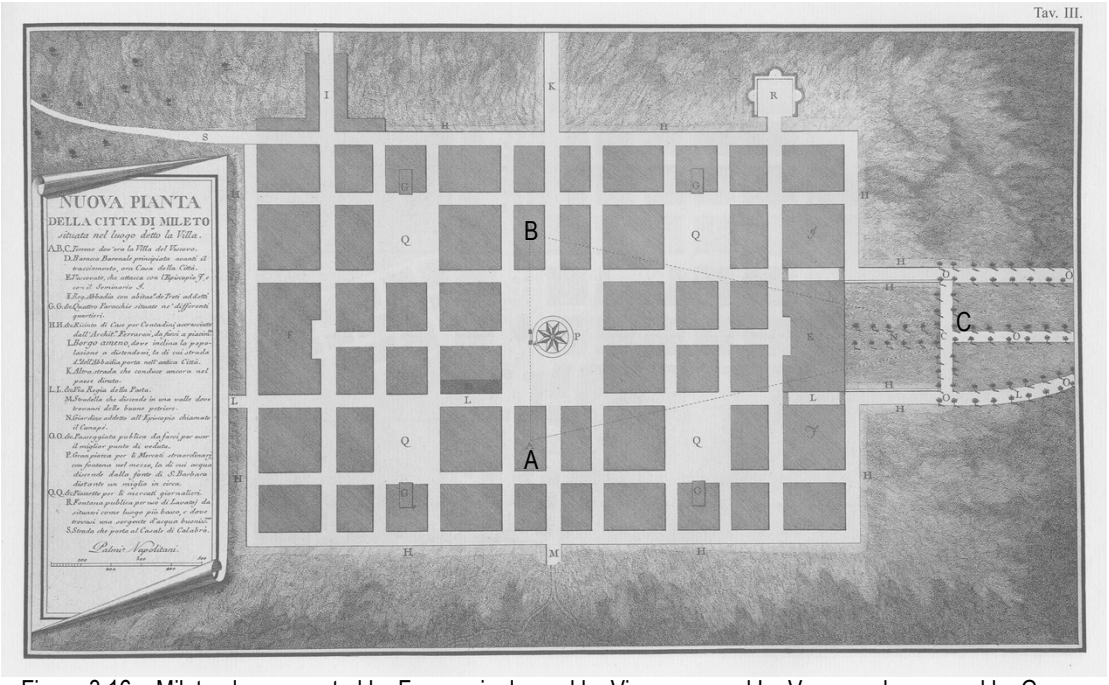


Figure 3.16 – Mileto plan, executed by Ferraresi, planned by Vinspeare and La Vega, and engraved by Guerra (Rubino, G. E. 1992, 51, plate no.II)

The choice of this site, also a favourable location for commodities (especially fodder), was a compromise dictated by the need to be close to the ancient center and especially to the crops, as Winspeare and La Vega declare in a missive to Pignatelli: "We would have liked the soil to be better, for building foundations, this being all clay; but as long as you do not want to move the new city more than a mile away from the destroyed town, you will not find any better within these outlines."[99]

The urban design was based on the recommendations of a team composed of the engineers Winspeare and La Vega[100] and executed by the royal architect Ferraresi, a student of Milizia[101] in Rome. Ferraresi was also responsible for the planning of other Calabrian towns: Sant'Eufemia, Seminara, Bagnara, Borgia, and Cortale (*Figure 3.08*). As previously discussed, Ferrarese signed the plates as *inventore* in the *Istoria* of 1784[102] as well as the designer of six urban plans, with Winspeare and La Vega (both belonging to the *Corpo degli Ingegneri Militari*) mentioned in almost all rebuilt towns,[103] included Reggio. According to Principe, the engravers and other involved technicians were marginal in the Neapolitan scenario – with the exception of Sines, Vanvitelli's student, charged with reconstructing Tropea – and certainly completely foreign to the culture of Calabria.[104] Vanvitelli judged all military engineers of this generation negatively, ironically characterizing La Vega as someone "who knows as much about architecture as I know of astronomy and differential calculus."[105]

According to the historiography, there was another technician involved in planning and reconstruction activities in Mileto, namely the engineer Frangipane.[106] The specific initiative of each of these engineers is unclear, except in relation to the presence of peasant houses called *recinti* (literallly fences), distinctive of Ferrarese's planning. Intended as monocellular row houses, these constitute the urban boundary, closer to the crops. At Borgia these can be found in a linear layout, at Sant'Eufemia close to the gardens, while on the map of Cortale they are not drawn but their position is reported in the caption. According to Principe, although ghettoisation of the peasants cannot be identified, these dwellings relegated peasants specifically to the peripheries and can therefore be understood as serving the will to maintain control and the traditional social order.[107]

Focusing on the urban layout of Mileto, it should be noted that the original plan is composed of a rectangular grid of fifty blocks of variable dimensions, bounded by a set of roads of 30 or 40 palms in width (approximately 8 or 10 meters), in compliance with art. 4 and 5 of the *Istruzioni* (*Table 3.02a*). The roadway system consists of eleven parallel north-south roads and seven roads in the east-west direction. There are five

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[99] "avremmo desiderato che il suolo fosse stato migliore, per fondare gli edificj, essendo questo tutto cretoso; ma semprecchè non si avesse voluto trasferire la nuova città ad una distanza di più miglia dalla già distrutta, non se ne trova migliore in quei contorni." (Principe, I. 1976, 344)

[100] The team of engineers belongs to the roman *Academia di San Luca*, with other students, such as Marvuglia, Mylne, Schiantarelli, and Sintes (Pezone, M.G. 2003, 76). Belonging to the elite of the Parthenopean entourage, the Spaniard Francesco La Vega is mainly known as the director of archaeological excavation in Vesuvian towns rather than for his role in the Calabrian reconstruction (*Chapter 1*, *section 1.3.3*) (Pezone, M.G. 2003, 73).

[101] Milizia was crucial for Ferrarese's training by *Principi di Architettura Civile* (1785) marked the transition between the ancient treatises and the technical manuals of the 18th century (Milizia, F. 1853) (Munafò, P. 2002, 54).

[102] For other scholars, the invention is attributable to La Vega as referenced by (Mauri-Mori, G. 1909, 89-90).

[103] Terranova, Fiumara di Muro, Polia, Poliolo, Sant'Agata di Reggio, and Francavilla are cited in archival documents (*Cassa Sacra*, *Atti vari*, b. 318, fasc. 30, cc.10r-11v).

[104] (Principe, I. 1976, 167) (Rubino, G. E. (ed.) 1992, 20)

[105] Extract from a missive sent by Vanvitelli to his brother Urbano on 28 April 1759: "i quali sanno di architettura come io di astronomia e calcoli differenziali". Vanvitelli's missives are published by Strazzulo (Strazzullo, F. 1976).

[106] The planners Winspeare (sometimes spelled Vinspeare) and La Vega are indicated at the bottom of Vivenzio's plates. Although Frangipane is not mentioned in the archival sources consulted by Principe, this scholar quotes that Albanese mentioned Frangipane as a collaborator in Mileto's rebuilt (Albanese, F. 1975, vol. 2, 424).

[107] (Principe, I. 1976, 217-218) (Rubino, G. E. (ed.) 1992, 20)

squares, with the main (double) square located at the centre of the plan.[108] The public spaces are thus the hinges of the new tissue: the central square with a fountain for the *straordinarii mercati* (extraordinary markets) – a recurrent principle in other newly rebuilt centers – and four side squares for the daily markets onto which parish churches face. The total surface of the new city amounts to about 22 hectares – almost equal to rebuilt downtown Lisbon (although Lisbon's population density was roughly quadruple at the time).

Mileto's plan as represented in Vivenzio's treatise (*Figure 3.16*) is schematic and does not include information on the socio-typological distribution of the buildings in the blocks, unlike other contemporary projects, except as regards the location of the mentioned peasant houses, conceived as row buildings in the outskirts of the town. Each building block is drawn as a single undivided shape whereas the illustration of Palmi (also included in Vivenzio's treatise) shows the roof plans, the built areas, the public spaces, and the semi-private areas (i.e. courtyards). Other information about Palmi is provided in the drawing published by Serrao,[109] including the elevation of each unit block. This urban model reflects the principles set out in Filarete's treatise (mid-15th century) and Scamozzi's treatise (early 17th century), with the addition of communitarian elements typical of the 18th century, proportioned to the small scale of Calabrian towns, such as the boulevards for expedite evacuation, the visual axis, and the peasant dwellings. Antecedents of the regular layout can be found in several cities, such as Paris, Edinburgh, London, Turin, as well as within the Neapolitan Kingdom, according to the planned expansion of symmetrical squares and straight streets in the Sicilian eastern towns rebuilt after the 1693 earthquake ($7.4M_w$).[110]

Like almost all newly-founded towns (except Filadefia – replacing the ancient Castelmonardo – with its square layout), [111] the selected geometric shape of its perimeter – within which the nascent society would have been organized – is rectangular, as well as all orthogonal building blocks. This chessboard layout, in which certain axes and blocks are emphasised, would have been "able to render a hierarchy of values to the urban space" ,[112] in contrast to the other radial forms which are instead organised around *perfect* geometrical figures (circle, square, hexagon, or octagon).[113] The regular grid pattern of the town contrasts with the surrounding natural setting that recalls the "picturesque" of the plates included in *Istoria.*[114] Mileto's urban grid consists of oversized blocks, embellished at the corners by private palaces with more significant architectural features. In compliance with the article 19 of the *Istruzioni* (*Table 3.02b*), all blocks are characterised by large inner courtyards (called *bagli*). [115] These spaces cannot be considered as outdoor shelter during earthquakes and later became vegetable gardens. Conceived as a legacy of country life, they were for the most part later filled by other constructions.

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[108] A hierarchy of squares and its buildings can be found also in Palmi, on-site rebuilt with new regular layout planned by G. Battista de Cosiron (*Figure 3.09*).
[109] (Serrao, E. 1974)
[110] Forty cities were rebuilt, among which Noto (Tobriner, S. 1982), Àvola, Occhilà (renamed Grammichele), Ferla, Sortino, Ispica, Buscemi, and Ragusa.
[111] Filadelfia's foundation was based on utopian egalitarian presuppositions: in a non-hierarchical urban layout, every citizen would be able to define their own place in the new physical and social reality.
[112] "in grado di restituire sullo spazio urbano una gerarchia di valori". (Principe, I. 1976, 222)
[113] The hexagon or octagon shapes are preferred by Ferrarese (sometimes spelled Ferraresi), as stated in his treatise *Corso di Architettura Civile, divisa in tre parti: bellezza, commodità, solidità* (1774), art. 1, *Disposition of a City*: "If allowed by the terrain, it would be desirable to use a hexagonal or octagonal shape so that the different neighbourhoods would not be too far apart from each other and so that it would be easier to exercise cleanliness". *Ita*: "Se il terreno poi lo permette sarebbe desiderabile, che le si potesse dare una figura esagona, o ottagona, affinché i diversi quartieri fossero non troppo gli uni dagli altri lontani, e che vi si possa più facilmente esercitare la pulizia."(Rubino, G. E. 1992, 112)
[114] As regards the graphic representations in the publications of the 18th century about the Portuguese and Calabrian earthquakes, see Keller's research (Keller, S.B. 1998).
[115] (Principe, I. 1976, 378)

3.5.2 *Mismatches between the original and the executed plans*

A comparison between the planned layout of the town and its real execution shows several discrepancies at urban and typological levels. While it is not possible to pinpoint exact reasons for these, mismatches must have arisen from the ways in which the aprioristic model conflicted with the privileges of the local elites – the baron and the clergy – as well as with the basic demands and traditional habits of the ordinary inhabitants at large.

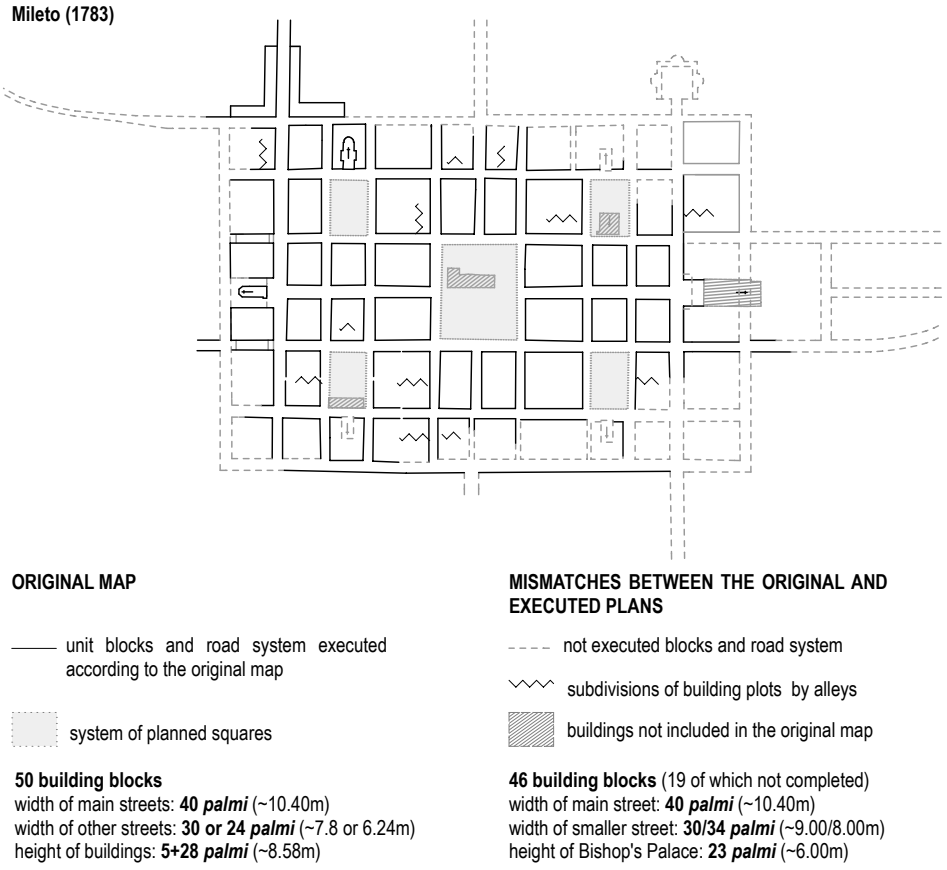

Figure 3.17 – Mileto plan: mismatches between planning and execution(© S. Stellacci)[116]

Elements which were planned but not executed include the park with tree-lined avenues drawn just outside Mileto's perimeter in the original map (*Figure 3.16*), the public fountain with washrooms, and two of the four parish churches. Other alterations to the original plan include the erection of two clergy-owned constructions, the Church of *Cattolica* and the Bishop's Palace, both executed in places originally designed as public squares In the four sides of the town, the alignment and the regularity of the street fronts is consistently lost (*Figure 3.17*).

Analysis of the land subdivisions as identified in the cadastral maps (dated to 1907 and the current one) does not provide easy recognition of the building types belonging to the first building phase. In fact, subdivisions of original quarters were frequently made in order to increase the number of building facades on the main streets and the number of low-income dwellings elsewhere, as can also be seen in Seminara (*Q1* in *Figure 3.18*).

[116] *Figure 3.17* was redrafted by the author of this thesis from the map published by Maretto (Maretto, P. 1975, 34) by adding the text and the indication of the alleys in the executed plan. Mileto's building blocks were also redrawn by overlaying Vivenzio's plan to the executed plan in a more schematic map by Zinzi (Zinzi, E. 1994, 90).

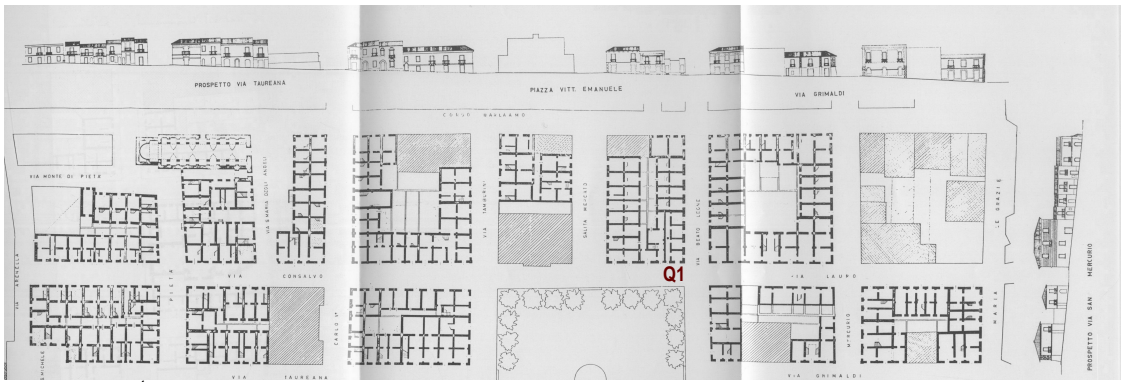

Figure 3.18 – Building fronts facing the street: Seminara map and main elevation, extract from (Maretto, P. 1975, plotboard no. 8)

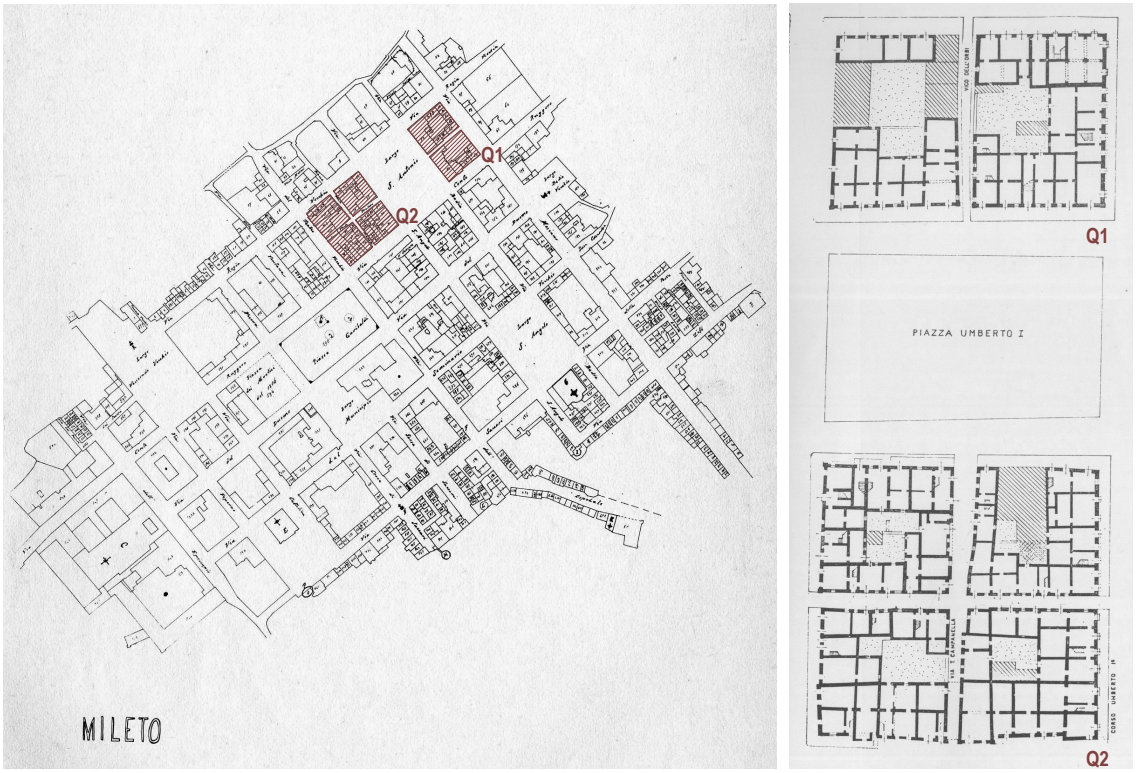

Figure 3.19 – Fragmentation of unit blocks: Mileto's map dated 1980 (AA.VV. 1982) *vs* on-site survey, extract from (Maretto, P. 1975, plotboard no. 12)

The quarters were subdivided by narrow alleys – called *strittuli*[117] – as shown in *Figure 3.19*: in Mileto, single blocks (*Q1* and *Q2*) were divided into two and four sections respectively. These fragmentations do not necessarily cause a high visual impact on the main facade of the edifices – which can indeed maintain a stylistic coherence – yet they do involve a relevant decrease in the seismic resistance of the building blocks. In fact, the capacity of each block to work as a unit was compromised due to a large number of structural discontinuities and dissymmetries introduced over the years.

In addition, these subdivisions of the blocks do not comply with *Borbone* provisions that established a ratio between the width of streets and the height of the buildings for safety and health reasons.

[117] (Principe, I. 1976, 331)

In Maretto's thought, these conflicts arose from two morphological aspects, the first common to other *ex novo* towns, and the second specific to this case study. Firstly, there is a discrepancy between the presence of different types of the buildings regrouped in single building blocks: various ordinary constructions – in band, terraced and in line, *palazzotti* overlooking the squares – *versus* the single large rectangular blocks, whose volume is interrupted by a single courtyard. These serial constructions along the roads or between landlocked axes, embedded into the rectangular blocks, reflect the new habits, differing from the previous local housing types (predominantly bi-or mono-cell types) arranged on a linear settlement.

Secondly, Maretto identifies the longitudinal development of the city and thereby the discrepancy between the geometric axis of the urban layout (*Via Duomo*) and the functional axis where citizens' activities are concentrated (*Corso Umberto I*). Principe contests this idea, considering these two road axes complementary to each other. [118]

[118] (Principe, I. 1976, 253-255)

3.5.3 Urban tissue of Mileto after the 1908 earthquake and recent building expansion

The symmetry of the late 18th century plan of Mileto – enclosed in a rectangle and organised around a barycentric square – was partly compromised by the building expansion along the longitudinal east-west axis. This axis corresponds to the main direction of peninsular route (*corso Umberto*); it became more important than the parallel *Via Duomo*, which is overlooked by the Bishop's Palace[119](*Figure 3.20*).

However, it should be noted that the enlightenment road system and its hub are still legible nowadays in plan and in elevation, in spite of severe earthquake damage in 1908 and many other invasive works.

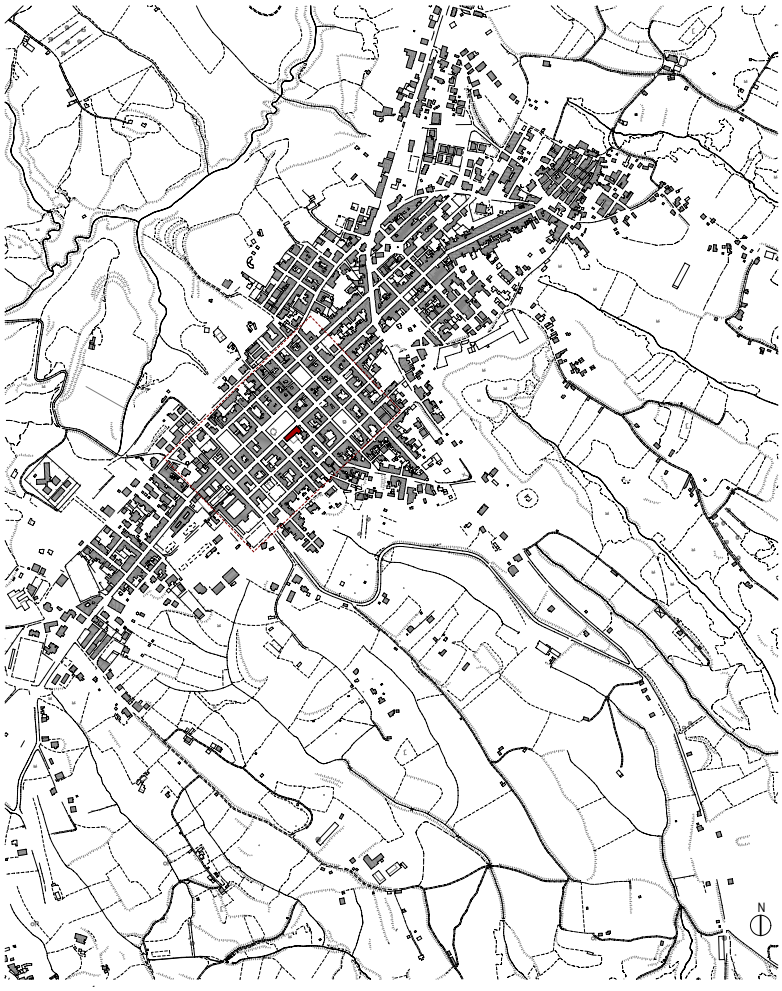

Figure 3.20 – Current cadastral map of Mileto: late 18th century town perimeter (red line) and the Bishop's Palace (© S. Stellacci)

It is also self-evident that such building expansions, anchored along the existing road axis, would have been organised as linear aggregations and not according to the squared block units introduced by La Vega, Winspeare, and Frangipane.

The most striking difference between *Borbone* and *Pombalino* interventions can be grasped in this specific aspect in terms of urban models.[120] After the early stage of the post-seismic reconstructions, the *Pombalino* construction system is assimilated and declinated in different layouts while remaining in compliance

[119] (Cataldi, G. 1974, 153)
[120] A broader perspective of this comparison is delineated in *Chapter 4*, *section 4.2*

with a specific proportional and construction system. Although lacking their own "erudite rigour",[121] these buildings – integrated into the new aggregative logic of the urban blocks or influenced by the contextual constraints – were widely erected in many districts of Lisbon until the middle of the 19th century.

Maretto interprets the weaknesses of the post-seismic planning as symptomatic of the contemporary crisis of the urban planning owing to the irreconcilable conflict between the rural (and poor in general) and the elitist societies, a clear symptom of the discrepancy between the rationalistic-institutional culture and the historical-environmental culture. The scholar points out that the Baroque and classical palaces were included in the new urban planning, unlike the ordinary architecture that would have demanded a deep analysis of the local building type. A greater attention to the habits of the local communities – overlooked by the Neapolitan officials and foreign observers – should have been taken into account in order to successfully implement the plan.

The importance of detailed morphological analysis of the traditional urban tissues that should precede all post-seismic reconstructions was clearly shown by Caniggia and Sartogo during the rebuilding of Venzone (North of Italy) in 1976-1979. Guidelines for the specific purpose of rebuilding this town *in situ* was set up based on the census of the pre-earthquake traditional buildings, the main road axes and the monuments of Venzone, conceived as a collective memory of local community to be preserved. Thanks to the involvement of all inhabitants, the destroyed buildings were catalogued divided into the main type (*tipo portante,* meaning bearing type) and the synchronic variations according to the solar orientation.[122]

Focusing the attention on Calabria region, the local building type built pre-earthquake is a minimal elongated unit, consisting of a single cell with a small exterior facade, the minimum to allow access to the house and ventilation.[123] The mono-cell type with bicellular depth was assumed as the key unit, able to be widened by side aggregations (two arrays of this unit) and in height by the addition of two or three floors. Moreover, the square epitomizes the morphological and dimensional abstractness of the original plan, as seen in Mileto.[124] According to Principe, *Borbone* planning – defined as *urban transplant*[125]– fails to meet its aims due to a convergence of different factors, such as insufficient attention to internal roadways, lack of commitment to the implementation of land estate reform, and lack of involvement of the local inhabitants.[126] These aspects lead to the inability to change the socio-economic system, leaving it welded to a backward micro-feudal paradigm.

Even if the virtue of each reconstruction planning standard (e.g. ratio between height of the buildings and the width of the streets, the reinforcement of masonry walls by the timber skeleton) is beyond question, the anti-seismic principles are meaningless when not incorporated into a comprehensive system executed synergistically:

> "The width of the streets or the height of the buildings did not mean anything if not included into an urban pattern able to interpret the needs of the society on which it had been imposed from above, nor could the simple wooden skeleton be executed

[121] "sem o rigor erudito da projectação inicial (...)".(Silva, R.H. 1997, 81)
[122] (Sartogo, F. 2008)
[123] (Maretto, P. 1975, 138-139)
[124] Some limitations of the plan, suggested by Principe, such as the oversize of the courtyards and squares (Principe, I. 1976, 378) have overcome throughout a gradual appropriation of the own site by the local community.
[125] (Principe, I. 1976, 375)
[126] The substantial difference between the Calabrian reconstruction activities and the Sicilian antecedents can be addressed in this specific aspect; the latter involves a more democratic renewal.

> if the speculative mechanisms underpinning the distribution and assignment of the land were not legislated together with the structure of the houses."[127]

Advancing Principe's arguments further, the complexity of the social and economic tissue in this region is a factor; however, the material reconstruction of the urban space and its buildings should have been executed according to a more prescriptive and effective system. The official body should have demonstrated the way to comply with these key principles from urban to architectural and construction scales, and this should have entered the collective consciousness. However, although the key anti-seismic construction principles were well understood by the Neapolitan engineers, these 18th century works failed to convey them to the collectivity and thus prevent the amnesia that would mark the 20th century up to today.

In shifting focus from the earliest phases of Calabrian cities' reconstruction to its recent years, Baratta's analysis can clarify some key aspects about the effective structural reliability of each building, distinguished according to the materials (masonry reinforced with a wooden skeleton or unreinforced, and *brest*) and number of floors (from one to three). Disregarding any disparities between the existing building and its original plan, this analysis can identify the 1908 post-quake effects (7.1M_w) case by case (*Table 3.03*). Regarding Mileto, useful data for understanding the vulnerabilities of the buildings and the types of required reinforcements are also included.

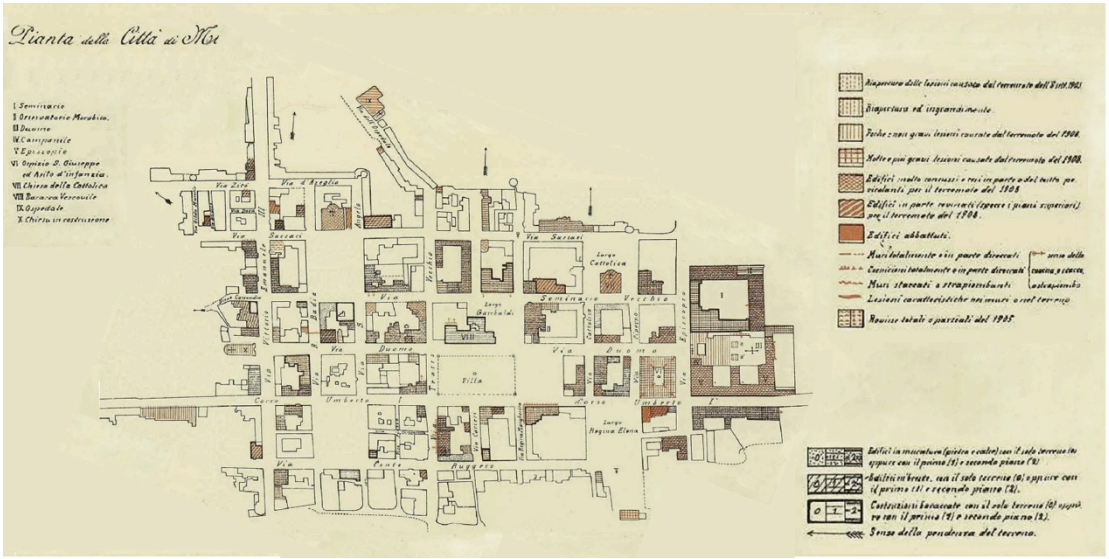

Figure 3.21 – Map of Mileto (Baratta, M. 1908, plotboard no. XVI)

The effects of the 1908 earthquake are well synthetized in Baratta's drawing (*Figure 3.20*) and reported:

> "Almost all of the buildings in Mileto have a single upper floor and a few have two floors. Most of them have been damaged, especially in roofs and in shifted tiles: many cornices fell, mainly on the facades facing north-east or south-east, and many walls partially; not many floors were thrown to the ground but it was necessary to demolish a number of others. (…) It should be noted that the damage caused by the other earthquakes, despite tie bars and rebuilding works, has now

[127] "la larghezza delle strade o l'altezza dei fabbricati non significavano nulla se non si fossero inseriti in una maglia urbana in grado di interpretare le esigenze della società su cui era calata, né la semplice armature in legno poteva essere proponibile se non si fossero regolati, insieme alla struttura delle case, i meccanismi fondiari e speculative che presiedevano alla loro distribuzione e assegnazione." (Principe, I. 1976, 335)

occurred in the same places but with more serious extent, reducing a number of houses that were previously considered low-damaged to really ruinous conditions.
In this circumstance the barrack-houses have also given good results: those with a simple ground floor have remained unscathed or have little damage; those with an upper floor have had some failure. (…) Finally, among these buildings, I would also note that the bishop's barrack (18th century), executed with the Borbone system after 1783, although somewhat deteriorated over time, has remained in good condition."[128]

Dozen *case baraccate* in Mileto are identified by a thick black line in *Figure 3.21*: buildings composed of a single floor or in a few cases of two floors, in rectangular or square plots. As mentioned before, besides the lack of continuity in the execution of *Borbone* system,[129] other original intentions were not fulfilled in the newly reconstructed towns. In Mileto, the initial ambitious intentions probably arose from the memory of the prosperity of the town prior to the earthquake – especially during the Norman Age[130] – and the optimistic perspective that this town would become a driver for a macro-scale economic upturn in the surrounding areas.

Table 3.03 – Summary table of categories of earthquake damage as surveyed by Baratta (Baratta, M. 1908)

<table>
<tr><th colspan="2">Degree and type of damage</th><th colspan="2">Building type and number of floor</th></tr>
<tr><th>Building damage</th><th>Wall damage</th><th rowspan="11">Ordinary buildings divided according to their construction system</th><th rowspan="11">Churches</th></tr>
<tr><td>Reopening of cracks caused by the earthquake of 8 September 1905</td><td>Totally or partially ruined walls</td></tr>
<tr><td>Reopening and elargments [crack of 1905]</td><td>Totally or partially ruined</td></tr>
<tr><td>Few and not serious cracks caused by the 1908 earthquake</td><td rowspan="2">Detached and overhanging walls</td></tr>
<tr><td>Many and serious cracks caused by the 1908 earthquake</td></tr>
<tr><td>Severely and partly unsafe buildings due to the1908 earthquake</td><td rowspan="3">Cracks in the walls and in the ground</td></tr>
<tr><td>Partially ruined buildings (especially their upper floors) due to the 1908 earthquake</td></tr>
<tr><td>Downed buildings</td><td rowspan="2">Total or partial ruins after 1905</td></tr>
<tr><td>No damage</td></tr>
</table>

Currently, the historic core of Mileto looks unfinished "with a chessboard-inspired pattern arranged directionally, although not integrally, and axially, although not exclusively".[131] Specific historical, political, and

[128] "Gli edifici di Mileto hanno quasi tutti un piano superiore e pochi due: nella loro grande maggioranza sono rimasti danneggiatissimi specialmente nei tetti, che ebbero le tegole in gran parte spostate: caddero molti cornicioni in prevalenza quelli nelle facciate rivolte a NE o a SE ed in parte molti muri: pochi furono i piani atterrati ma parecchi però fu necessario demolire. (…) E' da notarsi che i danni causati dagli altri forti terremoti, nonostante le catene ed i lavori di riattamento, si sono ora riprodotti negli stessi luoghi ma in proporzioni più gravi, tanto da ridurre delle case che si dicevano poco danneggiate, in condizioni veramente rovinose. Ottima prova hanno dato anche in questa occasione le case baraccate: quelle con il semplice piano terreno o sono rimaste illese oppure hanno sofferto ben poco; quelle ad un piano superiore ebbero qualche guasto. (…) Infine tra queste costruzioni ricorderò pure che la baracca vescovile (VIII) innalzata con sistema borbonico dopo il 1783, sebbene un po' deteriorata dal tempo, è rimasta in buone condizioni". (Baratta, M. 1908)

[129] On-site surveys of timber-framed buildings in all rebuilt Calabrian cities should be further developed in order to understand the effective extent of this anti-seismic heritage and its resilience.

[130] Mileto achieved its greatest splendor with the Normans, especially with Ruggero il Bosso – the son of Tancredi d'Altavilla – who in 1058 established his court in the town by nominating it the capital of the region and setting up a mint (Fagiolo, M.; Cagliostro, R.M. 2002, 692-3) (Naymo, M.M. 2002).

[131] "(...) un impianto a scacchiera direzionato, anche se non integralmente, e assializzato, anche se non univocamente." (Maretto, P. 1975, 150)

religious circumstances conditioned the extent of the building program in Mileto, as well as in various other new rebuilt towns (e.g. Palmi, Seminara).

Public spaces in Mileto, today being empty of the cultural value intended by their original court-appointed engineers, have lost their original coherence. However, at architectural scale, the group of buildings of the earliest rebuilding phase stand apart for their urban *decor* expressed through the plastic treatment of the exterior walls in a Renaissance-Mannerist style. A set of unplanned alterations (e.g. inclusions, divisions, and merging of housing plots) have compromised the architectural and structural authenticity of Mileto's historical core. Today, on-site analysis of the *case baraccate* previously surveyed by Baratta reveals evidence of additional reconstruction works from the first decade of the 20th century onwards, as testified by the material characterisation of the external walls composed of regular rows of more recent stones. In other cases, their walls have been plastered by a concrete-based layer, obscuring those features that would allow easy understanding of their degree of authenticity.[132] These alterations should have been prevented by public conservation strategies, monitoring the works carried out by private owners of buildings within the historical perimeter. The rehabilitation and reuse of palaces overlooking the squares, together with a large number of residential constructions, should be a priority for fostering more extensive urban renewal (*Figure 3.22*). Furthermore, dissemination of knowledge of the traditional construction techniques should be seen as an important vehicle for bonding the local identity of nearby post-seismic reconstructed towns, for example those belonging to the Gioia Tauro plain. Although essential, the rehabilitation of a single building (or a block) is insufficient in the absence of an integrated strategic plan, which must first aim at strengthening the settlements along the counter-ridgeline path. A straightforward intervention should also include improvement of the regional road infrastructure. Moreover, if the lack of involvement of ordinary citizens was the weak point of late 18th century reconstructions, future renewals at local and territorial levels should not neglect it.



Figure 3.22 – Late 18th century corner buildings in the historic core of Mileto (© S.Stellacci)

[132] e.g. Taccone-Gallucci Palace in Mileto (*Chapter 4*, *section 4.2.1, Figure 4.01*)

3.6 Final comments

Human settlements are a synthesis of the mutual interpenetration of nature and history. In accordance with the dynamics and the cyclic nature of the development of the settlements in the mainland,[133] Calabrian towns and their inhabitants were frequently displaced according to different contextual demands[134] and the geo-morphological features of their region.[135] Following a progressive occupation of the territory over the centuries from upstream to downstream, the settlements were first organised after the Greek and Italic *acropolis*, then the Roman *oppidum*, fortified medieval villages, and finally as grid-shaped towns under the aegis of the central government of Naples.

The history of many towns in *Calabria Ultra* (the south of the region), especially those belonging to the Gioia Tauro plain[136] (on the rugged Tyrrhenian coastline), can be fully understood by taking into account the immense damage from the severe seismic sequence of 1783. Unlike the displacements of the previous territorial phases, the late 18th century transference of the towns to new settlements and other urban additions to the ancient tissues should be framed as comprehensive reformist measures imposed by the central authority. This epoch saw this region at the toe of the boot acquiring awareness of its own territorial identity as its reconstruction attracted attention from outside the bounds of Neapolitan kingdom; this historical experience can be viewed as a sort of socio-political laboratory, the last test bed of the central government's policy.[137]

Under the reign of Carlo III (r.1759-1788), the proposals for town planning and building practice embodied European enlightenment thought and resulted in the proactive approach of the Neapolitan officials. In the wake of the 1783 disaster, many towns were rebuilt with a new chessboard pattern, whose wide, straight streetscapes were delimited by regular building blocks. As imposed by the group of experts from Neapolitan Royal Academy of Sciences and Letters – of whom Winspeare, La Vega, and Ferrarese were the most noteworthy personalities – preference was given for the new towns to be sited in the lowlands and in proximity to waterlines, crops, the old towns, and pre-existing main arteries.

Earlier examples of the simultaneous planning of many towns and the use of seismic-resistant constructions can also be found in southeastern Sicily, following the 1693 earthquake. Enlarging the scope of the analysis from this region to the South of Italy (in Campania, Lazio, Abruzzo, Calabria), physical evidence long before the 18th century testifies to the existence of local culture of timber-reinforced stone masonry. Leaving aside the controversy regarding the continuity of vernacular timber-framed construction *vs* the foreign influence from the

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[133] According to Muratorian scholars, the theoretical pattern of the Italian peninsular territory can be subdivided into: (i) a spontaneous cycle (from upstream to downstream: pre-Roman processes of structuring); (ii) a planned consolidation cycle (from downstream to upstream: romanization processes); (iii) a spontaneous cycle of reuse (from upstream to plain: post-Roman medievalization processes); (iv) planned "consumption" cycle (from upstream level: modernization processes) (Cataldi, G. 1974) (Caniggia, G.; Maffei, G. 1993).

[134] In addition to the historical events analysed in *section* 3.*2.1*, some villages (*fondali*) were abandoned throughout the 14th-15th centuries for tax-related reasons, followed by agrarian destructuring. Some references are provided by Principe (Principe, I. 1976, 22).

[135] Most of all, having being hit in 1315, 1349, 1456, 1461, 1646 and again in 2009, L'Aquila is an exceptional case of cultural attachment to the place.

[136] This lowland – the second largest alluvial plain in the region (after Sibari) – can be viewed as an autonomous territorial unit. Looking to the future, a strategy of development based on these historical landscape studies could form an alternative to longitudinal development along the Apennine ridgeline, thereby preventing abandonment of the settlements on the plain and deterioration of its rural environment (Cataldi, G. 1974, 174).

[137] (Placanica, A. 1985, 29)

reconstruction of Lisbon, the importance of this planning phase for urban tissues can be fully grasped by analyzing the governmental requirements laid out in *Istoria* (1783, 1788) and in *Istruzioni* (1784).

It is interesting to note that in Portugal the absence of (or the failure of researchers to find) [138] any detailed construction drawings not imply a lack of consistency and homogeneity of the *Pombalino* buildings. Conversely, the well-documented Neapolitan model for the construction of *case baraccate* does not correspond to any tangible constructions due to its low feasibility, only manifesting in general principles that have been incorporated into modern anti-seismic science.

Knowledge of this construction system in *case baraccate* is hampered by the position of the skeleton, embedded in the rubble stone or on the internal surface of the facade, and concealed by the thick layer of plaster (so-called *pareti intelaiate*). Similarly to L'Aquila in April 2009,[139] much of the traditional anti-seismic technical culture has been understood from examination *in situ* in the ruins of subsequent earthquakes.

Diving into the analysis of pre-1783 timber-framed constructions in Calabria should not cause us to forget that these anti-seismic devices were employed in only a minority of the whole building stock due to local communities' cultural reticence toward employing wooden structures, the expensiveness, and the laboriousness of this technique. Despite the remarkable seismic response of this construction system, *case baraccate* fell in abeyance after the early reconstruction phases as the trauma of the disaster began to fade –[140] as sadly noted by Baratta after the earthquake of 8 September 1905. The surveyed Calabrian building blocks at this time were: "weak houses unsafe by themselves, which are powerless to withstand the violent tremors affecting the soil on which their fragile foundation is based, crumble, falling into the piles of tragic ruins under which the inhabitants are miserably buried in unspeakable pain, with the immense suffering that follows all great catastrophes."[141]

Within the multifaceted scenario of Calabrian post-seismic rebuilding, the scope of this analysis has narrowed down to the case study of Mileto, whose importance resounds in over a dozen pages describing this

[138] The law of 12 June 1758 does not include any construction details. Original architectural drawings or details of any *Pombalino* building in this district have so far not been found, with the exception of seventy main facades republished in the *Cartulário Pombalino* (Viegas, I. M. (ed.) 2006), which includes a few extracts of plans. Different hypotheses have been formulated by several scholars to explain the reasons for this surprising lack of technical drawings, considering the extent of the building works in this epoch. Raquel Henriques da Silva analyses the building contracts, which also lack any construction drawings, and deduces that the knowledge of construction processes must have been grounded on building practice predating the 1755 earthquake. A set of rules was *a priori* consolidated and understood by different categories of workers (e.g. carpenters, stone masons, and bricklayers) (Silva, R.H. 1997). Santos dismisses the hypotheses that the plans would have never been drawn due to lack of interest in how the tenants would occupy the space, and also that these documents would have been destroyed during the fire of 19-20 November 1863 in the Town Hall. Santos indicates other factors as reasons for the absence of original drawings, such as the deterioration of the documents, the absence of a requirement to provide drawings for municipal approval, and also the lack of reproduction processes at the time (Santos, V.L. 1994, II.1.2.3).

[139] In addition to the timber skeleton embedded in the walls, external anti-seismic devices, such as scarp walls, contrast strings, tie rods, and bolted end-plates, were already known and discussed in literature. See references indicated by (Nobile, M.R.; Scibilia, F. (ed.) 2016, 155-168).

[140] Giuliani finds an explanation to the global tendency to forget effective anti-seismic solutions in the difference in time between the building and the man's life and especially in his apotropaic attitude (Giuliani, C.F. 2011, 26).

[141] "case deboli e di per sé stesse mal sicure, che impotenti a resistere ai violenti fremiti che interessano il suolo sul quale sono poggiate le loro fragili fondamenta, cadono infrante, riducendosi in cumuli di tragiche rovine sotto cui restano miserabilmente sepolti gli abitanti con gli inenarrabili dolori, con le inaudite sofferenze che susseguono a tutte le grandi catastrofi."(Baratta, M. 1906, 253)

town in the *Istoria* (1784).[142] Having been relocated two times in different yet nearby sites, Mileto exemplifies the sense of temporariness and the collective effort over the centuries to set up a new order against natural adversity.

In accordance with the general principle envisaged by Winspeare and La Vega to relocate the towns from morphologically diverse areas (spurs, hills, and ridges) to flat zones, the new Mileto was erected away from its old village, in a nearby lowland surrounded by a stretch of small streams. Enclosed in a rectangle of 360 x 550 m and organised around four squares with spacious streets designed in relation to the height of the nearly fifty blocks, this town embodies the Neapolitan intentions towards a comprehensive reform.

At the same time, enlightenment principles for the improvement of knowledge and living conditions came into collision with the will to maintain the pre-earthquake *status quo*, based on a feudal system dominated by the local priviliges of the baronies and clergy. The inequality of land distribution was not adequately challenged by the *Cassa Sacra* (1784-1796), the governmental body formed to finance rebuilding in this vast territory.

The mismatches identified at urban and typological levels between the planned and executed towns arose from the abstractness of the original map[143] and the impossibility that the local communities would accept an aprioristic model in conflict with their traditional habits and settlement models. The planned layout of Mileto was oriented so that it crossed the previous main arteries (*Strada Regia delle Calabrie*, the roads to the old town, and the roads to the stone quarry), but it did not take the traditional practices of local communities into account. Linear settlements would have been preferred to bi-axial or symmetric layout, as well as mono or bi-cell types met the requirements of Calabrian humble people more than large rectangular building blocks. Accordingly, successful reform was undermined by the multiple demands of the population who were not inclined to modify their own civic and construction models.

[142] (Sarconi, M. 1784, 37-51)

[143] Filadelfia is a case in point of utopian blueprint of the Enlightenment. In fact, two of the four landmark gates, planned by the architect Serrao and the philosopher Stillittano, were not executable due to its orography and pre-existing pattern of settlement (Zinzi, E. 1994, 93).



CHAPTER 4 – Urban iconographies and anti-seismic constructions: a multi-storey building for renting in Lisbon *versus* the Bishop's Palace in Mileto

4.1 Introduction

> "The scar as a measure of time, memory of separation, part of the healing process, on the other hand, reveals the impossibility of the man to exercise a full control over the environment in which he lives".[1]

The physical artefact is unavoidably rooted in its own cultural milieu, as seen in the two case studies discussed in this chapter: a building in the low centre of Lisbon (1780-1789) and the Bishop's Palace in Mileto (1784-1795). These are empirical results of the collective enterprise in the aftermath of the earthquakes, which dramatically showed the vulnerability of the former streetscapes.

These selected buildings testify the complex processes of healing the scars of disaster and the attempt to reassert human control over natural forces. In addition to being representative and almost coeval examples of the anti-seismic heritage in their respective contexts, these case studies were also chosen for their specific features and for the opportunities to carry out on-site surveys: during the ongoing rehabilitation works of the Lisbon building and during a temporary phase of negotiation between Mileto municipality and the present owner of the Bishop's Palace. This negotiation (unsuccessful so far) was initiated by the community's concern about the advanced state of neglect of the palace – one of "the many wrecks carried to shore by history".[2]

It should be noted that these case studies stand out from their nearby coeval buildings: located at the border between the old town and the Enlightenment tissue, the *Pombalino* case study belongs to an atypical block unit for its elongated conformation; the *Borbone* palace is also atypical because it was not included in the original map of the rebuilt city. Interestingly, it is also significant for its high construction accuracy and for its resilience against various adverse conditions.

This comparison shall encompass the urban morphology and a smaller-scale analysis of architectural/construction features. All of these aspects are strictly intertwined. The technique determines the building geometry; the structural principles influence the whole layout.

Correspondences and mismatches between legislative recommendations and the buildings themselves shall be discussed, progressing from the urban ensemble to the street-scale dynamic, finally examining the interior layout of the single building plots in detail. Single or multiple components of these buildings shall be ideally decomposed in an isometric view in order to unveil the logic of the components' features and their mutual

[1] "La cicatrice intesa da un lato come misura del tempo, di memoria della separazione, parte del processo di rimarginazione, dall'altra riflette sull'impossibilità per l'uomo di esercitare il controllo totale sull'ambiente in cui vive." Sommariva's comment on the photographic exposition in which she participates together with Dobrucka, Hallgrímsdóttir, Ishikawa, Kikuchi, Richon, and Quadri (Maggia, F.; Serra, T. (eds.) 2017).
[2] "dei tanti relitti portati a riva dalla storia" (Strappa, G. 1995, 16)

relationships. Their tangible materiality will be transmitted through a sort of *radiographic analysis* aimed to freeze fragmentary and temporary stages before a new intervention obscures (or invalidates) them.

The description of these selected constructions and their narratives might interest a wider readership generally not given the opportunity to see these building structures revealed. This graspable memory may represent a vehicle for a closer relationship to the past and the re-appropriation of their own local culture.

4.2 Comparison of *Pombalino* and *Borbone* post-earthquake building stock

A comparison between ordinary constructions built from the late 18th century in Portugal – the so-called *prédios de rendimento pombalino*, i.e. multi-storey buildings to be rented for multi-families – and the group of *case baraccate* distributed within many urban centers in the southern provinces of Italy is approached based on literature review and on-site observations. Architectural, typological, and construction features are discussed with the aim of raising awareness of the importance of safeguarding this anti-seismic building stock in its original material and spatial configuration.

4.2.1 Architectural and typological features: a preliminary approach

The *prédios de rendimento pombalino* epitomize the paradigm of modern life in a capitalist society, whereas *case baraccate* are houses rooted in a rural environment of low population density: multi-tenant apartments to be rented above bustling shops at street level[3] – storefronts of a renascent capital – *vs* simple Calabrian houses with granaries or cellars at the ground floor. Many differences between *Pombalino* and *Borbone* post-seismic rebuilding are readily apparent: (i) economic purposes – the speculative interests of the middle class together with the ambition of the public authorities to modernize the public image of Lisbon[4] in contrast with the lack of forward-looking Calabrian planning, intending maintenance of the former socio-economic system; (ii) location – the centrality of the rebuilt downtown area *vs* the peripheral scattered locations of the Calabrian towns; (iii) the predominant sense of verticality (due to the required density of occupancy) of Lisbon's rebuilt area *vs* the horizontal development of *Borbone* dwellings (low constructions with elongated facades).

Regarding this last point (iii), it should be noted that the original *Pombalino* building model was more similar to the Calabrian houses in that it emphasized a more horizontal layout. This is in contrast to how the *Pombalino* buildings came to be executed – Silva identifies only two examples faithful to the early Portuguese model: Caldas Palace (1770) in the square of the same name and Cruz-Alagoa Palace[5] (1757-1762), the latter characterised without mincing words as "a monotonous sequence of windows arranged as in a train"[6] (*Figure 4.01*). The palace in *Rua das Trinas* nos. 70/80, with its elegant composite proportion in its Mardel-style curved roof, can be also viewed as a full expression of Maia's intentions, together with the three-storey building in *Rua Palma* nos. 3/13.[7]

The enlightenment framework drew on a convergence of local and international experiences. Military engineers, respectively belonging to the Lisbon Public Works Office and the Royal Academy of Naples, played a central role. In both contexts, the city planners were concerned with the idea that the renewed cities should comply with public safety and aesthetic requirements, for example directives concerning the water mains and sewers, but overlooking specific recommendations about the apartments to be rented, leaving this up to the

[3] Almost all blocks of the Lisbon reconstruction were intended for renting. The Corpus Christi convent in *Rua dos Fanqueiros*, built twice in the same place, firstly by D. Luísa de Gusmão in 1647 and again after the 1755 earthquake, is emblematic of the vocations practiced in its district: trade and storage activities at the ground floor and the mezzanine, as well the residential function of the first floor apartment coexisted with the contiguous convent, as testified by archival documents and on-site evidence. These spaces were rented out by the friars of Corpus Christi convent as described by Santos (DGEMN 2004, 124-131).

[4] (Rossa, W. 2015, 311)

[5] (França, J.A. 1994) (Silva, R.H. 1997, 82)

[6] As described by Matos: "uma sucessão monótona de janelas dispostas em comboio" (França, J.A. 1994) *apud* (Figueiroa-Rego, J. 2016, 49).

[7] This building is identified by Pereira in the adjacent area to *Baixa Pombalina* (Pereira, N.T.; Buarque, I. 1995, 88-89).

owner.



Figure 4.01 – (top) Cruz-Alagoa Palace (1757-1762) on *Rua Escola Politécnica,* Lisbon (photo by A. Seródio, 1968, PT/AMLSB/SER/S05015); (bottom) Taccone-Gallucci Palace (1785) in Mileto

Another common point of these experiences is that each building was designed by ordinary technicians, so that *Pombalino* is defined as "architecture without master";[8] in Calabria, the Neapolitan engineers were charged

[8] "arquitectura sem mestre" (Barreiros, M.H. 2013, 28) or – better defined – "mestres-de-obras" (master builder) (França, J. A. 1987, 8). See (Silva, R.H. 1997, 121-122). However, some renowed architects were certainly

with the urban location and layout, while other worksite decisions – including distribution, construction, and decorative features – were entrusted to local (probably Campanian) ordinary architects.

The first impression from the *Baixa* streets or from archival photos is that the urban setting overrides the single artefact. The military-like uniformity of this district (also visible in all of *Pombalino* Lisbon)[9] firstly arises from a system that guaranteed allotments in accordance with the former ownership rights, according to the provision of 12 May 1758. The reconstruction in this district was financed by private owners who were compensated by the central authority according to their former rights. City directors also guaranted preferential rights to the owners of adjacent lots.[10] As issued by Manuel da Maia, the buildable plots were attributed to the previous land owners or, in some cases, to those with a certain purchasing power.[11] The identification of owners' rights and the resulting definition of the equivalent commercial value of the new lots were possible thanks to the information recorded in the Property Register. The former area of each owner was divided by the depth of the new lot, constant on each street – 58 or 75 palms in the downtown area – resulting in the proper width of the lot frontage to be assigned to the land owner. The owners had to build within a maximum period of five years, otherwise the lot became public and was re-sold.[12]

A well-defined system of compensation was required to overcome the main differences between the new planned area – which included larger public spaces and regular plots – and the former urban tissue. The old urban layout was characterised by high commercial value and variability of lot dimensions with undersized frontages, whereas a more rational building system was implemented in the new area. Under the supervision of Alexandre José Montanha, chief surveyor of the inspections, the new downtown area was divided into seven zones according to the economic value of the buildings. The new owners had to execute the buildings within a period of five years in compliance with a set of urban, formal, and construction principles. As stated by Eugénio dos Santos, the *Pombalino* building's elevation should vary according to *a priori* hierarchical importance attributed to the streets.[13] On the principal streets they would have been composed of four floors, i.e. ground floor, first floor (with balcony), two additional floors, and an attic with dormer windows.[14] Moreover, in buildings facing streets of lower importance, the balconies have to be replaced by windows. Regardless of the location in the new rebuilt areas, a legal minimum frontage of 26 palms (corresponding to 5.72 m) was introduced in the 1759 building license to

involved, for example Vincenzo Mazzoneschi (set designer of São Carlos theater) was appointed to implement alterations on executed buildings in as four contiguous plots in *Rua dos Fanqueiros* nos. 142/150, 152/160 and in *Rua da Madalena* nos. 125/133 (DGEMN 2004, 98-107).

[9] It should be noted that *Baixa Pombalina* together with the adjacent areas on the hills (Chiado, Bica, Carmo until São Roque, on one side, and São Mamede, São António da Sé and north until Portas de Santo Antão), has been defined as *Lisboa Pombalina* in Portaria no. 740-DV/2012 (Barreiros, M.H. 2013).

[10] Considering the large amount of capital required for cases of public expropriation, the procedure for the attribution of building plots, based on equivalence of values, was a successful strategy.

[11] *Dissertação*, 2nd part, 3-5 (Ayres, C. 1910, 33-36) (França, J. A. 1987, 86-87) (Santos, M.H.R.; Sagarra I Trias, F. 2011) (Santos, M.H.R. 2014)

[12] However, as explained by Raquel Henriques da Silva – taking up França's studies, and then confirmed by recent studies (footnote 84) – these reconstruction works generally took longer (França, J. A. 1987, 118) (Silva, R.H. 1997, 40-43). In some cases, at first only the external facades were erected to provide an image of aesthetic embellishment of the nascent hub, later followed by the execution of the interior spaces in a second phase.

[13] Santos underlines slight discrepancies between the prescriptions included in the 1758 plan and the execution. The main north-south streets (defined *nobles*) should have measured 60 palms (13.20 m), but in fact measure 61 palms, and the secondary streets vary from 36 to 43. *Rua dos Fanqueiros* measures 50 palms (11 m), instead of 40 palms (Santos, V.L. 1994, II.3.3.19).

[14] As established in the construction licence of 12 May 1758, natural light and ventilation should be provided by window dormers. They also allowed the preservation of the timber structures and other features, and impacted the streetscape image (França, J. A. 1987, 331-337).

guarantee safety and minimum living conditions.[15] Therefore, despite the large number of owners, the large extent of buildable area, and the long run-time of the works – over seventy years[16] – the uniformity of the rebuilt district was guaranteed by the use of a basic module, as clearly expressed in the drawings included in *Cartulário Pombalino*.[17] The uniformity of these buildings, expressed in the symmetry of doors, windows, and heights, is a fundamental innovative aspect of this district, as introduced for the first time by Manuel da Maia in the second part of the *Dissertação*.[18] Beyond the disposition of the blocks at right angles (divided by streets of 60 or 40 palms), this uniformity is defined by the sequence of vertical bands of elevation, i.e. a door on the ground floor, a balcony on the first floor, and windows in the two upper floors. Such conformity in the execution of facade layout according to the importance of the street is one of the unique features of *Pombalino* planning.

Contrary to what happened in downtown Lisbon, the new layouts of the Calabrian towns were subject to the interests of the private owners of the lands where the new tissues were planned. Accordingly, as seen in the case study analysed in *section 4.4*, private buildings in Mileto would come to occupy public space or otherwise cause the alteration of the planned map, or vice versa – the planned blocks were not executed, nor were the road axes towards the crops in Palmi. Even the square perimeter of tiny Sant'Agata di Gallina did not reach completion. Further building expansions would ignore the rectangular blocks and their central courtyards proposed in *Istruzioni* and would be arranged along rows, as a summation of mono-cellular units; these revisit typical aspects of the medieval settlements, which were developed along rural axes rather than around venues and public squares.

In regard to the architectural feature, other differences can be underlined in comparison to downtown Lisbon. More significant palaces generally face the squares or occupy the corners of the blocks, but, at the same time, serial architecture, whose features are similar to other buildings in the minor streets, can be found along the main axes. In addition, the following influential factors of the final effect of the rebuilt area should be more extensively discussed in light of this research:[19] zoning according to social class and the fragmentation of the building blocks (i.e. the introduction of new minor road axes and unplanned or spontaneous subdivisions of the building plots by each owner).

The first aspect, the specific attribution of the building plots to the inhabitants, reflects the desire to maintain separation between different social classes. New towns were planned divided into distinct neighbourhood units,[20] as seen in Mileto. Another emblematic case is Filadelfia, despite having first been conceived as a model of egalitarianism: one wealthy family would occupy an entire block (*isola*), while a poorer family occupied only half of one (split by alleys), with other subdivisions according to their economic power.[21]

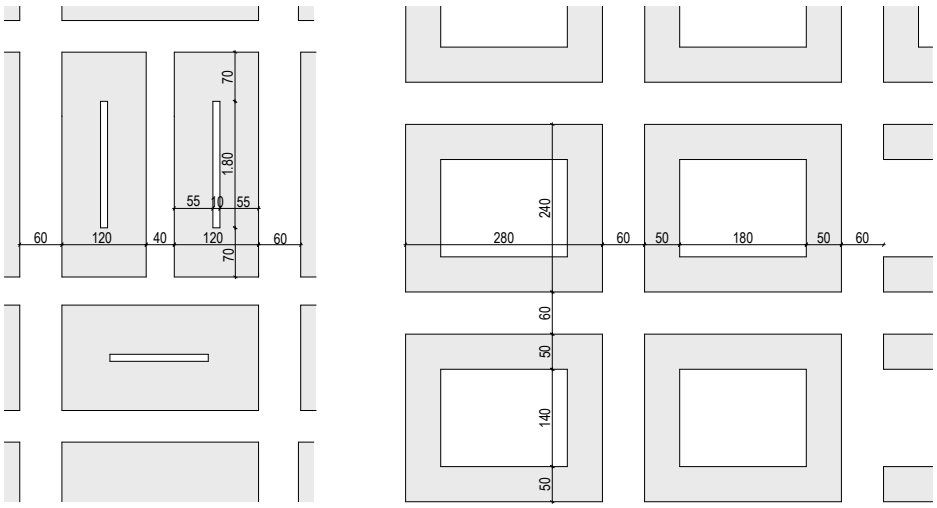
Principe discusses the plot assignments and some internal disputes between local communities. The owners of those lands, where new centres would be built, were entitled to receive the cadastral income of the land corresponding to the same amount they had received before the erection of the buildings, i.e. as agricultural land, without any increase deriving from the new urban income.[22] The Neapolitan engineers chose specifically less

[15] (Silva, A.D. 1825-1830)
[16] see footnote 84
[17] The majority of these drawings, restored in 1991-1993, was executed when the Marquis de Pombal was count of Oeiras between 1759 and 1769 (Viegas, Inês Morais (ed.) 2006).
[18] (França, J. A. 1987, 88)
[19] *Chapter 3*, *section 3.5.2*
[20] (Principe, I. 1976, 331)
[21] (Maretto, P. 1975, 176)
[22] *Istruzioni per regolare la riedificazione della città di Reggio*, *Chapter 2*, art.8, published by (Aricò, N.; Milella, O. 1984)

expensive lands in order to facilitate the timing and reduce the costs of the reconstructions. The owners would have been somewhat compensated, because new building expansion would have involved nearby lands – belonging to the same few owners – and thus they would have been able to receive an increase in income.

Unlike the unplanned fragmentation of the quarters into multiple small varied building plots, the drawing of roads and their proportions in relation to building height are consistent with the Neapolitan purposes within the initial town perimeter.[23] The majority of the buildings should have only one floor (*Istruzioni*, art.15). The other ordinary buildings should have only one floor above the ground floor, reaching 28 palms (7 m approximately), whereas the buildings owned by wealthy townsmen (in general bordering the squares) could include another floor for a height of 38 palms (10 m approximately) (*Istruzioni*, art. 14,17). Similarly to the *Pombalino* district, there is a ratio between building height and the width of the streets: 40 palms for the main streets in the city and 24 or 30 palms in the minor streets.

In both post-seismic plans, the block is conceived as a key element of town planning reform in terms of spatial and formal layout: the selection of rectangular or square blocks influences the layout of each building plot, which should face the street on one side and the courtyard on the other (*Figure 4.02*). While the blocks were never broken by additional minor axes in downtown Lisbon, an unplanned space defined by dark narrow alleys was introduced by the Calabrian townsmen to reduce the oversized blocks and fill the voids. This later occupation of the urban territory is in conflict with the concerns underpinning the *Istruzioni* (1784) for the health of the inhabitants by intending adequate ventilation via careful location of the new settlements and their building blocks.[24]



Lisbon
(*Rua do Ouro*, *Rua Augusta,*
unchanged layout)

Bagnara
(northeast coastline, layout strongly
altered post-1908 earthquake)

Figure 4.02 – Ratio of building block and its patio in extract of downtown Lisbon, adaped by (Mascarenhas, J. 2004, 176) *vs* extract of Bagnara, based on Vivenzio's map (Rubino, G. 1992, plate no. VII) (dimension in palm)

The blocks are also strictly related to the interior patio, a semi-private space complementary to it. In *Baixa Pombalina*, the rational organization, the high density, and the multiple tenants in the same building units were a new paradigm of the habits of modern citizens, in contrast to the previous domestic spaces. In this

[23] *Chapter 3*, *section 3.3.2*
[24] *Istruzioni*, art. 3, 24, 25 (Aricò, N.; Milella, O. 1984)

scenario, the patio (*lograduro*) – a vestige of land in the buildings' rear (*quintal*) – was a necessary ventilation space for multi-private tenants. In the majority of cases, this small external space has been gradually occupied by new volumes to accommodate new functions dictated by daily requirements. Conversely, the semi-private outdoor spaces of Calabrian blocks was deemed oversized at that time (*Figure 4.02*).

Another difference can be observed in the point between the roadway and the floor plan of the buildings: in compliance with the permit of 14 October 1758, there are no front door steps in downtown Lisbon – which is remarkable due to its rugged topography – while in Calabria external steps are common. These are in compliance with Vivenzio's recommendation to execute a plinth, the ground floor three palms higher than street level in order to avoid direct contact between the timber components and the soil. The access to the warehouses of the ground floor are from internal staircases and from external steps (*Figure 4.03*). It is interesting that the London streescape (with its external staircases) is indicated by Vivenzio as a model for the small Calabrian new towns.[25]

Another aspect that impacts the new streetscape of these cities is the narrow dimensions of the balconies. Simple jambs, aligned with the stone sill or with their vertical pieces simulating the corboles of balconies,[26] confer a sense of austerity. Gone are the timber overhangs and balconies – flat, aligned, and regular facades of the rebuilt Lisbon are enriched by narrow balconies, single or common to multiple tenents (*varanda corrida*).[27]

The Vitruvian triad seems to persist in the *Borbone* provisions, in view of the stability of the construction (the height limitation, the connections of all components) and the simplicity of the architectural style (in geometry and layout – including the prohibition of heavy stuccos and overhangs). In accordance to the *Istruzioni* (art.17), the recommendations for Reggio rebuilding (or renewal) are even more accurate with regard to the balcony and the facade layout:

> *"*All the stone balconies will be removed, but even if they want to maintain or build some, this should be as far from the corner as possible, and its overhang, and the thickness of the inside part [its width] is regulated in such a way that the center of gravity of the same stone falls in the middle of the fabric. The best solution, however, if you want to build a balcony, will be to erect it above the house-door, and support it by the pillars themselves which will provide an ornament at the entrance. What is meant for balconies applies to every other structure leaning against the houses, resting on corbels, or similar supports, and also the cornices that must have a small overhang, and be made of lighter stones." [28]

[25] Explanation from Vivenzio's treatise of plate no.1 (Principe, I. 1976, 369).
[26] see *Figure 4.16*, windows of the 2nd and 3rd floor
[27] Every decorative features including corbels, overhangs or metallic rings to ties horses were forbidden in the permit of 16 June 1759 (França, J. A. 1987, 178).
[28] From *Istruzione per regolare la riedificazione di Reggio*, Chapter II, art. 15, 3: "Si toglieranno tutti I balconi di pietra, ma quando pure se ne volesse conservare o fare alcuno questo sia piú lontano che sia possibile dal cantone, ed il suo sporto, e la grossezza della parte interna sia regolata in guisa che il centro di gravitá della stessa pietra cada nel mezzo della fabbrica. Il miglior partito però volendo far dè balconi sará eseguirlo sulla porta dell'edifizio, e farli sostenere dai pilastri medesimi, che serviranno ornamento all'ingresso. Ciocché si dice dé balconi s'intenda d'ogni altra opera addossata alle case appoggiate ai gattoni, o simili sostegni, ed anche delle cornici che devono avere poco aggetto, ed essere formato di pietre più leggere."

The roof shapes are also fairly different in these two groups of buildings. In Lisbon, the roof covers the attic, displaying influence from French rather than from German taste, according to Duarte.[29] Typical dormer windows, also composed of a timber skeleton, mark *Pombalino* buildings; Calabrian houses are instead covered by slightly inclined roofs, which in general are not habitable.

The internal layout of *Pombalino* buildings is fairly simple and repeated in height for achieving the best functional solution for rental use: two apartments per floor with a central staircase (*esquerdo/direito* or *risco ao meio* "right/left" plan or "with a line in the middle") or one apartment per floor (*singular* plan). Barreiros sees these allotments as experimentation with a non-codified type at this time.[30] The lack of typological planning resulted in different layouts in these contexts; while the requirements of the multiple tenants shaped the residential interior space in Enlightenment Lisbon, in the Calabrian towns the habits and budgets of the humble inhabitants led to simple, mono-cellular plots of double width, whereas the palaces were generally characterized by biaxial symmetry, with a central staircase. Aside from their internal distributions, all *Pombalino* buildings are multi-storey edifices based on vertical development, whereas two-storey blocks prevail in the new Calabrian towns.



Figure 4.03 – Front door street on *Via Seminario* in Mileto (© S. Stellacci)

Pombalino style is viewed as eclectic; its proto-neoclassical influences, strongly grounded in national military experience – whose greatest exponents were Manuel da Maia, Carlos Mardel, and Eugénio dos Santos – is influenced by French treatises and expressed following the styles defined by either Ludovice or Mardel.[31] França suggests also a Roman Baroque influence,[32] but economic constraints preclude the exuberance of any coeval forms as thought in Rome. For its parts, Calabrian buildings, incorporating a Renaissance-Mannerist style

[29] (DGEMN 2004, 85)
[30] Some of the plentiful literature is provided by Barreiros (Barreiros, M.H. 2010) (Barreiros, M. H. 2012) (Barreiros, M.H. 2013), or based on the inventory of furniture by Madureira (Madureira, N.L. 1992).
[31] Duarte underlines the influence of Serlio, an Italian architect with French training, as well as influence by other treatise writers of greater renown, including Blondel, d'Aviler, and Briseux (DGEMN 2004, 76-87).
[32] (França, J. A. 1987, 211-217)

rather than a Classical influence,[33] express a typical style of the central Italian regions, enriched by numerous elements repurposed from old constructions (*Figure 4.04*) and fined-worked railings in wrought iron. The edifices (*case palaziali*) are characterised by ashlar external wall surfaces and typical features of the former palaces. This latter aspect is observable in the height and in the openings' hierarchy through the prominence of the central door (the main access of the building, generally arched) to which, in the interior space, the central staircase corresponds. The features of the palaces are also expressed in decorative detail, e.g. lesenes and capitals, doorjambs, projecting cornices, refined corner stones, and the narrow balconies (*Figures 4.05*, *4.06*). Many original facades and their decorative features were altered by the new Liberty style or irremediably lost in later earthquakes, especially the projecting cornices.[34]



Figure 4.04 – Marble door jamb included in a late 18th century building in Mileto (© S. Stellacci)



Figure 4.05 – Late 18th century palace in Filadelfia (© F. Geremia)

Borbone buildings also embody a sort of expressiveness enriched by a certain constructive ingenuity. Uniformity instead prevails in the *Pombalino* buildings and palaces in terms of material and geometry, although the palaces are enlivened by the coupled central portal and balcony.[35] While systematic use of the Lioz stone and the

[33] (Principe, I. 1976, 336)
[34] (Baratta, M. 1908)
[35] Raquel Henriques da Silva rightly points out that from the end of 1780 *Pombalino* style evolved into *Mariano style*, which includes enrichment of the architectural volume, of the rhythm of the façade and – in some cases – the decorative embellishment of the atrium, as can be seen in the buildings in *Rua do Alecrim* (Silva, R.H. 1997, 122-124).

same dimensions of the components produced a more standardized and uniform effect in *Pombalino* buildings, decorative components made of brickworks were shaped according to the individual demands of the builder and integrated by *spolia* components in *Borbone* buildings. Indeed, the reuse of stone materials and marble artefacts was a common praxis in Calabria during the Normann epoch, as seen especially in Mileto, Gerace, and San Demetrio Corone:[36] giant corner lesenes, finely carved capitals and socles, door jambs, trabeated portal and neoclassic corbels, and continuous plinths throughout the building facade. These elements are fully integrated in the overall compositive layout but of a lesser importance, quality, and consistency, when compared to the Baroque buildings dating shortly before in Sicily and Lecce (Apulia).[37] While the Baroque in eastern Sicily was also developed during the post-seismic reconstruction works of the late 16th century, in Calabrian towns – including Reggio Calabria–[38] this style did not take root, and simpler composite schemes prevail. A Neapolitan influence, which in turn came from a Roman tradition imposed by Pietro da Cortona and Bernini, can be noted in the new Calabrian buildings.



Figure 4.06 – Late 18th century Serrao palace in Filadelfia (© F. Geremia)

[36] (Naymo, M.M. 2002, 59)
[37] (Maretto, P. 1975, 37)
[38] Ibid., 22

4.2.2 Comparison of some key construction aspects

In examining this heterogeneus antiseismic heritage, the most important typifing element is the presence of timber-framed structure. In Portugal and in the South of Italy, the load-bearing wooden components – although detectable through different diagnostic tests[39]– are concealed due to their susceptibility to decay from the peripheral masonry. Thus, a sharp difference between Portuguese and Italian buildings on one hand, and Northern European constructions (e.g. *Fachwerkhaus*, *maison à pans de bois*) on the other, can be established. Another fascinating traditional solution for covering the wooden skeleton of the exterior walls can be found in the dwellings in the historical centre of Kolin (Czech Republic), which declares the presence of timber components or infill (stone or brick surface) through a chromatic and material difference of the cladding.

A brief overview of the main aspects related to *Pombalino* and *Borbone* construction phases, some features (i.e. ground floor and upper floors) and their material characterisation is discussed below based on literature and other evidence:[40]

- *building processes:* A great deal of organization and planning at the building site was indispensable for the erection of the multi-storey *Pombalino* buildings. Carpenters and masons were the best paid of the workers, due to the high demand for them at this time.[41] Slight differences notwithstanding, the construction process was a well-defined system of rotations. In the first phase, the *cabouqueiros* executed foundations in those components (e.g. *estacas, longarinas, travessas*) which belonged to the pre-existing local technical culture, followed by the masons who executed structures for soil containment, masonry walls, and ashlars. Next a group of carpenters took over, erecting the timber system for all the floors at once. The vertical posts (*prumos*)[42] were placed, rising continuously for the entire height of the building above the ground floor by means of connections and carvings. The gross height was then divided into regular parts and the diagonal members (*escoras*) were introduced between each vertical post and the horizontal beams (*travessanhos*), in order to improve the bracing of the whole structure. Before the placement of the infill in the triangular fields of the timber skeleton, the structure was temporarily shored up by *travadeiras costaneiras* (timber struts jack) to prevent relative displacements.

Such an efficient and standardized process was likely hampered in Calabria by transport difficulties and the lack of prior familiarity with these construction techniques, as well as the reluctance of the communities to use wood due to expense and mistrust of its performance under varying weather conditions. In addition, the traditional relationship between the workmen and the final building – i.e. components were executed with knowledge of their specific location and function in the building to be erected – is likely to persist in the smaller Calabrian rebuildings, whereas it was definitely lost in the large-scale 1758 *Pombalino* programme.

The postcard in *Figure 4.07 c*aptures a scene in which the black-dressed Salvatore Borgia and magistrate Antonio Maria pose at a worksite where the skeleton of the building has not yet been enclosed in brickwork. This is the Borgia Palace (still existing) in Mileto, built with the *sistema barraccato* in the early 20th century. Despite belonging to a subsequent epoch, which likely involved more advanced construction phases,

[39] e.g. thermographic analysis (under specific expositive conditions: no wind, high temperature and high percentage of humidity) ultrasonic, and resistography tests.

[40] This comparison does not claim to be exhaustive. It covers only the points mentioned, while neglecting others such as foundation and roofing.

[41] They were daily paid 500 and 400 *réis* respectively (Sousa, F.L.P. 1923, III, 518) *apud* (França, J. A. 1987, 161-162). Monthly salaries of ship caulkers of this epoch amounted to 3,000 *réis*, while the carpenters and the infantry captains were paid 5,000 and 20,000 *réis* respectively (Santos, V.L. 1994, II.1.2.19).

[42] The term *prumo* (from Latin *plumbum-i*) indicates the instrument used for measuring the verticality of the wall or pillar, which consists of a weight hanging on a woven cotton string.

some observations can be noted in comparison with the Portuguese case. We can deduce that the construction of the wooden skeleton of the peripheral walls was followed by the work of the masons, who filled the fields defined by massive posts. The internal partitions were not executed at this stage, whereas in *Pombalino* buildings the internal skeleton was integral to guarantee the stiffness of the whole building and so was part of the earliest phases.

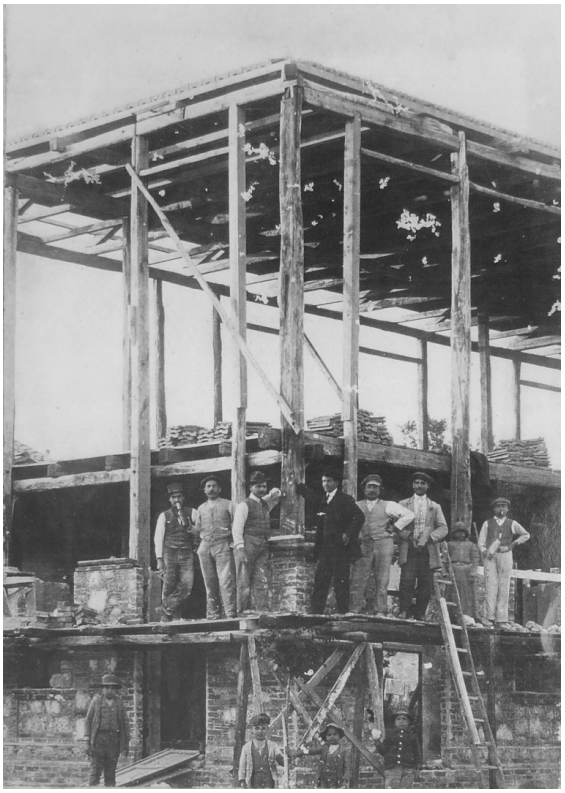


Figure 4.07 – Borgia Palace (1920s?) in the corner of *Via Badia* and *Via Seminario* in Mileto

In addition, due to the impossibility to meet the high lumber demand growth in Calabria, the drastic reduction of wooden components and their replacement by iron chains was proposed by Giovan Battista Mori as alternative solution to the governmental model of anti-seismic timber-framed house. Actually, the height of ordinary buildings was limited by Mori to 7.40 meters and the foundations and the connections of the walls would have been executed with particular attention in order to avoid large cracks and overturning of masonry walls.[43]

There is more about the construction processes which should be studied by on-site inspections of *case baraccate*, but what is noteworthy at this point is that the reduced availability of lumbers and the short memory causes progressive simplification of the building practice, the second factor also at play in the in the new buildings worsening in Lisbon.

- *construction systems*:

(i) *ground floor:* The majority of *Pombalino* buildings are grounded on masonry arches; wooden joists were not commonly executed, except to cover smaller spans, for example at the entrance. The use of masonry arches and pillars together with the thick peripheral wall prevent fire hazard and wood decay (due to presence of

[43] (Baratta, M. 1906) (Riccò, A.; Camerana, E.; Baratta, M.; Di Stevano, G. 1907) (Mauri-Mori, G. 1909, 88-99)

humid environments), and strengthen the system at its base. Conversely, the arches and stone vaults are not executed in the *case baraccate* because of the out-of-plane horizontal forces they cause.[44] Article 9 of the *Istruzioni* (1784) vaults are envisaged only for the under-ground level where this effect is counteracted by the soil.[45] In Calabria, the main vertical posts, which are connected to the joists and the rafters, are executed from the ground floor to the second floor. This is the main construction difference between these systems: the continuity of main vertical wooden posts from foundations to the roof in Calabria contrasts with the *Pombalino* use of timber posts only above the ground floor. In most of Calabrian buildings, wooden rough members were placed in the work site, whereas in downtown Lisbon lumber cross sections were almost standardized and regular. Low refined components can be found especially in the attic or mansard floor of these multi-storey buildings.

(ii) *upper floors*: *Pombalino* structure is based on a cage (*gaiola*) formed by an orthogonal grid of vertical panels (*frontais*)[46] and timber floors. Each panel consists of a set of triangles (a non-deformable shape), which improves the vertical shear strength, as well as resistance under the horizontal load. An almost perfect system was achieved through interlocking different structural elements to form Saint Andrew's crosses, where all connections guarantee the bracing of the structure. In the *Pombalino* buildings, above thick masonry pillars and stone vaulted ceilings of the ground floor, a three-dimensional timber frame above the first floor, reinforced by wooden cross-bracing components (10 x 10 cm or 10 x 8 cm), is designed to withstand seismic actions through the ductile behaviour of the joints and the satisfactory interlocking of each construction component. The ductility of the joints is directly related to the ability of the structure to deform nonlinearly without significant loss of strength, whereas the interlocking[47] increases the maximum load and stiffness of the connection. The type of the connections greatly varies according to the dating of building execution. The most common joints used are the half-lap joints, in some cases held in place by one or two nails, and less frequently, dovetail or mortise-and-tenon joints. In Calabrian buildings, the external walls of the *casa baraccata* (*pareti intelaiate*) were built with wood framing, while the thinner interior walls were made of wood and uncoated masonry, or sometimes with simple frames filled with brick, as in the *gaiola* system. The carpentry joints most employed in *case baraccate* are half-lap joints connected with pyramidal nails and *trait de Jupiter* joints (scarf joints with wedges). Each timber component is fixed by one or two (long) nails, unlike in *Pombalino* buildings, where many timber frame walls lack nails.

- *material characterisation:* A large amount of data on the materials characterisation of *Pombalino* constructions is discussed in literature, based on archival sources (e.g. budget documents) and on-site analysis.[48] What is emphasised is the large scale of the interventions and thus the high demand for raw materials, for which some concessions were granted by the central authorities, as shown to Stephens for his lime factory with sixteen kilns in *Alcântara* and to a glass factory in *Marinha Grande*; at the same time, the central authorities sought to

[44] The *volte contrastate* (contrasting vaults) typical in Abruzzo incorporate anti-seismic measures, as described by Carocci, who distinguishes those built before 1703, which are reinforced with timber tie rods in the extrados, from those reconstructed in 1703 (Nobile, M.R.; Scibilia, F. (ed.) 2016, 170).
[45] (Aricò, N.; Milella, O. 1984) see *Chapter 3*, *Table 3.01*.
[46] Over the centuries, the term *frontal* has been employed in Portugal for the traditional interior timber wall even though it was mainly applied as an internal structure wall during the recovery of *Pré-pombalino* houses in the post-earthquake reconstruction and, in particular, in the 18th century buildings. See (Leitão, L.A. 1896, 292).
[47] i.e. interaction between timber frame components infill, joint, surface finish.
[48] The technical knowledge was passed down through generations verbally or by Portuguese manuals (Oliveira, V.M. 1748) (Leitão, L.A. 1896). Among many scholars, Santos and Mascarenhas provide detailed information about the building materials (e.g. their provenience and qualities, measurement units) and the execution process of the mid-18th century in Lisbon (Santos, V.L. 1994) (Penn, R.; Wild, S.; Mascarenhas, J. 1996).

control the market prices of materials.[49]

Various types of wood species and genus may be found in the same *Pombalino* building. The wood components come from the Portuguese forest, i.e. *Quercus pedunculata*, *Castanea sativa*, *Quercus suber*, *Quercus ilex*, and also from other regions such as of Northern Europe, e.g. *Larix decidua* and *Pinus sylvestris,* which did not exist in Portuguese forests at the time. The cross section of the vertical posts are generally of 13 x 15 cm, while the horizontal components of 10 x 13 cm.

To prevent severe deformation or damage, the wood components were subject to an air drying process, since the auclave process was not developted at this time.[50] The filling of the timber skeleton was composed of irregular blocks of limestone and/or clay bricks, gravel, small ceramic elements, and mortar. The stone blocks came from the limestone quarry near Monsanto, while the lime came from the valley of Alcântara, with its 15th century furnaces. The stonework (*cantarias*) comes from Sintra and Mafra areas, where more resistant stones can be found. A particular type of mortar was prepared on-site with clayish sand and quicklime with the addition of small portions of tallow (vegetable or animal fat). The result was a remarkably waterproof mortar.[51] The gypsum was also often employed, though it is hard to find evidence of it. The thickness of the plaster[52] increased progressively up to 0.06 m, creating a mechanically resistant barrier, especially since the masonry filling itself exceeds the plane of the wooden structure. In addition to the good adherence of the original plaster, chisel marks were made in the timber skeleton in order to increase the roughness of the surface.

In regard to raw materials employed in Calabrian constructions, the recommendation included in the *Istruzioni* (art.10) to employ a well-seasoned and treated chestnut or oak wood was observed; in fact, Calabrian Chestnut is the most frequently used wooden species, due to its availability in the large wooded area from the northern Aspromonte foothills near Cosenza to the Ionian coast and slope of Sila.[53] Art.11 of the *Istruzioni* (1784) recommends pre-treatment of the wooden elements by removing their bark, charring or tarring the surface in order to prevent rotting, and finally surrounding them with gravel so as to avoid any contact with lime. *Borbone* walls were made of rectangular or roughly squared blocks of different dimensions. Some stone blocks were laid orthogonal to the wall surface in order to bind the multi-leaf walls. Other information on the type of filling is reported by Baratta.[54] Timber-framed houses in the countryside and in the villages, even at times in the city, were filled by raw bricks or clayish soil; the foundations and the door and window jambs were made of bricks or stone. Baratta, probably following oral accounts by local townsmen, indicates the habit of leaving the walls bare for two or three years – only covering them with plaster once they are well dried and the rain has made them rough outside.

[49] Protectionist policy was guaranteed by the Marquis of Pombal to this English entrepreneur, as well as an interest-free loan and exception from all taxes, as established by the Decree-Law of 15 May 1756 (França, J. A. 1987, 161).

[50] The wood coating of interior structure walls was generally treated with bitumens of clay and later with linseed oil. Depending on the type of the surface coating, the wood was then treated with glue usually of animal origin, e.g. “peel glue” (*cola de raspa*, scraped animal fluids prepared with white leather and peel skins), “strong glue” (*cola forte*, with skins and animal bones), or “English glue”(i.e.white leather and eel skins). The latter is not frequently encountered in the buildings due to its low durability (Santos, V.L. 1994, II.4.1.54-56).

[51] (Ibid., II.4.1.22)

[52] Santos argues that the colour was light tone in order to avoid the alteration or the blackening of the surface (Ibid., II.4.1.50)

[53] The extensive use of chestnut is mentioned in documents of the 15th and 16th centuries (Barrio, G. 1737) *apud* (Buccellato, R.M.D. 1993, 5). The wood of this tree was employed for ships and buildings, and its nuts were used for food, including animal fodder and chestnut-flour for very humble people (Buccellato, R.M.D. 1993).

[54] (Riccò, A.; Camerana, E.; Baratta, M.; Di Stevano, G. 1907)

The plaster was commonly fixed onto horizontal reeds tied with cotton twine,[55] nailed to the timber vertical posts of the partitions; a more elaborate technique consists of intertwined wooden strips, observed in the 18th century building in *Via Chiaravalloti* and *Via Incatenata* (Carmine district) in Pizzo.

In making a comparison between these systems, it is noteworthy that the *Pombalino* buildings contrast with *Borbone* buildings in the larger proportion of wood used and greater homogeneity of structural layout. The construction hybridism of *case baraccate* of the late of 18th century continued into their second generation and contradistinguishes them from the Portuguese system.[56] More extensively, the *Pombalino* construction system is typified by the homogenity and invariance of the main features in numerous multi-storey buildings or palaces in this area as well as in other districts of Lisbon. Conversely, the *Borbone* system does not embody a single construction type; in fact, several variants in terms of structural layout and devices for in-plane stiffing can be found. It varies considerably from double-bonded frames to single wooden frameworks placed in the walls at different heights. Some different types of timber-framed wall are described in literature: cases with diagonal bracings, e.g. a palace in Tropea in a district called *Baracche* and a demolished building in Filadelfia,[57] versus Bishop's Palace in Mileto, analysed in detail below, which has no such bracing. Other examples of timber frame walls have recently been observed by the author of this thesis in Rosarno (*Figures 4.08*, *4.09*, *4.10*), as well as in the 16th century building in Pizzo whose upper floor was probably executed to replace the attic after the 1783 earthquake (*Figure 4.11*).

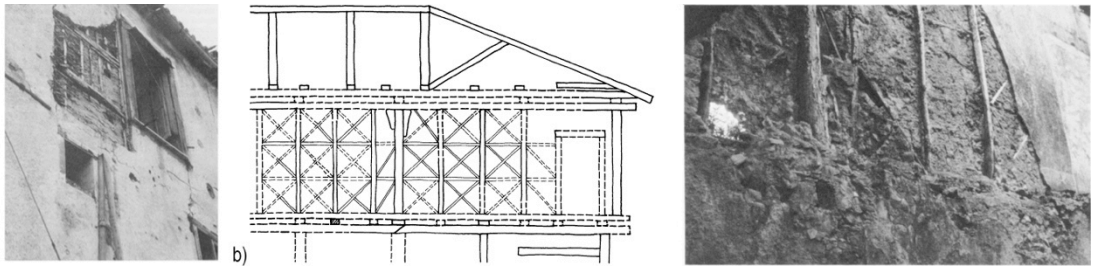


Figure 4.08 – Load-bearing walls in Calabrian buildings: (a) External masonry wall reinforced with timber skeleton and covered by wattle and daub infill, Cosenza (Ruggieri, N. 2005, 141); (b) Internal wall in Filadelfia (demolished) (Tobriner, S. 1983, 137)

Moreover, as emphasized by Tobriner,[58] Calabrian buildings have greater strength in their external facades than *Pombalino* buildings. *Pombalino* external walls are fashioned in stone masonry with a timber skeleton on the interior side that serves primarily to accommodate the wooden joists. The *Borbone* external walls entail a more complex system composed of horizontal beams connected to the vertical posts by long nails and half-lap joints. This series of vertical posts is arranged at a pre-determined distance from the corners, or where those walls are crossed by orthogonal interior walls,[59] as examined in case study 2 (*section 4.4.2.1*). Both timber skeletons frame each door-window (or window). On the basis of the surveyed case studies, Tobriner supposes

[55] The selected reed canes should be fresh (light green colour; their drying occurs after the application) in order to avoid *in situ* cracking (Bianco, A. (ed.) 2010, 77).
[56] (Tuzza, S. 2009) (Bianco, A. (ed.) 2010)
[57] The building in *Corso Italia*, Filadelfia is described by (Tobriner, S. 1983, 135-137); other references to *case baraccate* with diagonal components are included in the on-site post-seismic survey carried out by Baratta (Riccò, A.; Camerana, E.; Baratta, M.; Di Stevano, G. 1907, 17).
[58] (DGEMN 2004, 166)
[59] This latter aspect is very similar to the aforementioned *beneventana system*, typical of the Campania region (*Chapter 3*, *section 3.3.2*).

that the higher effectiveness of the *gaiola* system can be perceived by comparing the internal walls of *Pombalino* buildings and *case baraccate.* In the latter, low cross sections of the timber components and a lack of connections provide insufficient structural performance for the whole building.



Figure 4.09 – (left) Horizontal reeds in the Bishop's Palace of Mileto (photo by the author); (right) interwined wooden strips in 18th century building in Pizzo (© D.Ceravolo, Recol srl)



Figure 4.10 – Evidence of timber frame walls in private buildings in Rosarno (© F. Geremia)

Four common principles in these buildings may be outlined: (i) the regularity of the plan and elevation development; (ii) the behaviour of the building as a whole unit; (iii) the overall ductility; and (iv) the reduction of mass compared to ordinary masonry buildings.

The composition of these buildings is characterised by a clear layout with repetition of proportional systems. It is evident in the 70 facades illustrated in the *Cartulário Pombalino* and those drawn by Ferrarese.[60]

[60] (Rubino, G. 1992) (Viegas, Inês Morais (ed.) 2006)

The regularity of the layout both in vertical and horizontal planes induces regularity in the distribution of mass and stiffness. In both cases, the design and execution are based on a metric module where the whole and each part are commensurable. This commensurability is achieved through the fixed module (palms)[61] in elevation and plan to economize the construction process. The regularity in the mass distribution is due to the rigid logic of the alignments of the openings and the resulting constant ratio between the solid/void parts in the surface.

The second principle, the behaviour of the building as a whole unit, is achieved through the connection of the structural elements in the three dimensions of the building, thus reaching an overall balance. According to this principle both systems achieve structural strength through high material compatibility and the combined work of the orthogonal walls. The *box-like effect* that is achieved through the connection between the structural elements results in lower vulnerability for the entire compound. In fact, during an earthquake, the shear wall avoids or reduces the possibility of collapse, acting in a parallel direction to the imposed action.

The third principle – overall ductility – is the basis for the good performance of the system under earthquake strain. Under seismic actions, ordinary masonry, as well as timber members, have a predominantly brittle behavior. In the case of wood, the ultimate limit state and/or the collapse is reached predominantly in the linear field. In these composite structures the excessive brittleness of the wood is limited by the presence of the filling materials; on the other hand, the elasticity of the timber frame manages to keep the wall in its original position, at least for moderate displacements. Furthermore, the system is able to dissipate seismic energy thanks to the presence of the timber structure nodes that are not rigid enough to result in brittle fractures. Moreover, ductility is enhanced by the friction generated between the wall components, as well as at the interface between wood frame and masonry filling. Energy dissipation also takes place through cracks in the mortar joints and by expulsion of stones under seismic load.

Finally, the fourth principle is a result of the unique strength of the system. Due to the low specific weight and high strength (compared to a structure entirely of masonry), the seismic forces produce moderate acceleration in the framed structure, lower than in most of other kinds of structure, such as reinforced concrete or unreinforced masonry. Moreover, considering the timber structures' redundancy, there is effective solidarity in case of failure of a structural element wherein other force-carrying elements compensate and prevent a collapse of the entire system.[62]



Figure 4.11 – Inner load-bearing walls (*muri di spina*) with diagonal wooden members (post-1783) in the 16th century palace in *Piazza della Repubblica* in Pizzo (© D. Ceravolo, Recol srl)

[61] Indeed, the module is no longer an exact multiple of the palm (Penn, R.; Wild, S.; Mascarenhas, J. 1996, 9-10).
[62] (Ruggieri, N.; Zinno, R. 2015)

4.3 Case study 1: a multi-storey building for renting in Lisbon

Flanking the western edge of the hill on which ancient Lisbon stands,[63] you come across the selected case study enclosed in a quarter that defines the border between the newly rebuilt city and the old town[64] (*Figure 4.12*). This block is arranged along the north-south axis and is bounded by two streets – *Rua dos Fanqueiros* (the Drapers' Street previously called *Rua Nova Princesa*) and *Rua da Madalena* – both parallel to *Rua Augusta,* the *axis mundis* of the new urban tissue.[65,66] This case study was chosen for its location and because the structural skeleton of this building was completely revealed when the finishing was removed.

4.3.1 Cartographic grounds, perspectives on urban and household habits

The case study is included in a block unit of thirty-six plots, eighteen of which are situated side-by-side linked by a small common outdoor space, as drawn by Folque (*Figure 4.14*). Each building plot of this block is organised as a unit overlooking one of the streets (*Appendix C.1.1*).

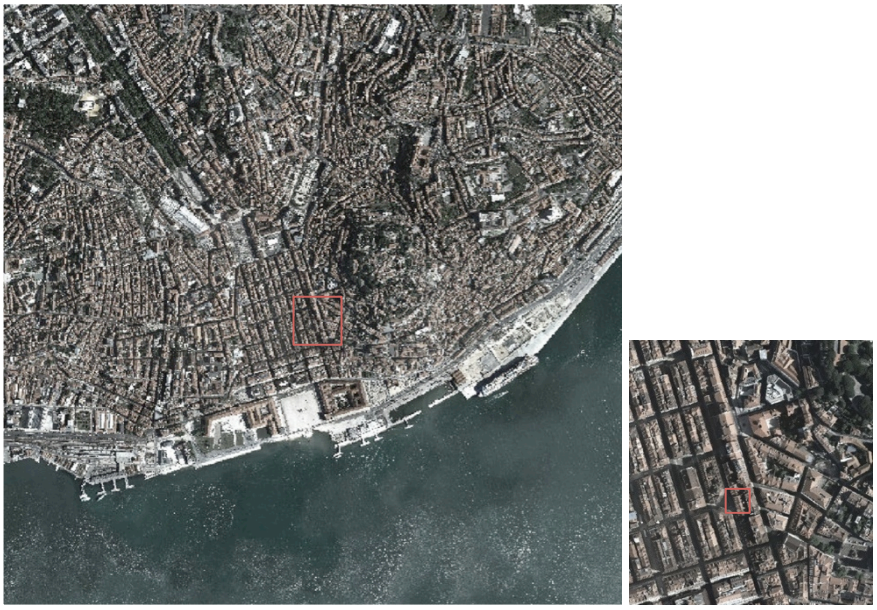


Figure 4.12 – Location of the analysed building block and plot in the downtown Lisbon (© S. Stellacci)

Among all the sixty-two blocks of this rebuilt district, it is by far the longest quarter since it is extended for 1,830 *palmos craveiros*,[67] corresponding to 402.50 meters.

[63] Elevated town locations were generally preferred for defence from the attacks and river floods: "the imaginary city (on the hill) of scripture". *Pt*: "a cidade imaginaria dos textos bíblicos" (Silva, C.G. 2008, 25).
[64] Two different habits have coexisted for a long time until now: the eastern part, e.g. *Mouraria*, *Alfama*, *Castelo*, and *Graça*, and the western rebuilt side (Barreiros, M.H. 2009, 19). Silva alleges that the main reason of the failure of the proposal of a global urban reorganization would be the lack of an integrated planning between these two areas (Silva, R.H. 1997, 46).
[65] *Rua Ourives do Ouro*, *Rua Douradores*, and *Rua Escudeiros*, covering the *Cano Real* in the 15th century, were replaced by *Rua Augusta* (Santos, M.H.R.; Sagarra I Trias, F. 2011, 310).
[66] *Rua Augusta* represented more than the main geometric axis of this district, since it was also viewed as driving force for real estate investment in all the surrounding streets. To this end, the legislative decree of 21 June 1773 sought to overcome delays by establishing that the parish council should attempt to execute the constructions of those buildings in *Rua Augusta*, later recouping the cost as these buildings were occupied (Silva, R.H. 1997, 39).
[67] Among the six types of Portuguese palm, *palmo craveiro* is the most important unit employed for the measurement of mass, volume, and length. Building proportions were influenced by this unit, while the *palmo da*

Apart from the elongated shape of this quarter, the high difference of height in the streetscape that is accentuated in *Largo Adelino Amaro da Costa* square should also be noted. It can be easily perceived a few meters away from this case study by passing through a *Pombalino* building recently turned into a public lift and service centre: here the difference in height between *Rua dos Fanqueiros* and *Rua Madalena* is approximately sixteen meters.[68]

As with every plot devoted to residential and retail functions, access to this building is made from the main street, probably due to the planners' intention to create multiple private properties and facilitate the transposition of the old tissue to the new.[69]

Interestingly, Sergeant-Major Monteiro de Carvalho drew a plan in the latter half of the 17th century, including four chamfered blocks to frame two churches, one of which – the São Nicolau church – would have been contiguous to the analysed case study. Both churches were ultimately executed at other sites and only one of these spatial openings created by the chamfering of the corner blocks was constructed: on one side this is the facade of the Corpus Christi convent,[70] while the chamfered blocks in the north were not executed.

Another mismatch between the earlier and the executed plans also regards the urban layout: this single block was first planned to be divided into four rectangular blocks, parallel to *Rua Augusta* and aligned to the surrounding plots (*Figure 4.13*, on bottom). The four transverse interruptions of the block intended by the 1756 map were hampered by the outline of the hillside slope (*Colina da Madalena*) and only reached at two different points: *Rua* (or *Escadinhas*) *de Santa Justa* and *Rua da Conceição* (*Appendix C.1.1*). These instead formed the boundaries of a single elongated block which can be identified in Duarte Fava's map of 1807, in Filipe Folque's elaborate watercolours of 1858[71](*Figure 4.14*), and in successive maps.

Apart from this mismatch, other slight differences between the initial map and the operational programme set up by the *Casa do Risco*'s engineers may owe to the need to adapt the planned settlement according to the topographical constraints and pre-existing structures.

The question relating to the improvement of the urban layout goes through the legislative provisions of this period, since the first part of *Dissertação* by Manuel da Maia (4 December 1755), when the idea to take an advantage by debris – for decreasing the elevation differences and to provide an adequate inclination for the rainwater drainage – was conceived.[72] Significant altimetric changes were made throughout this district during the *Pombalino* works. While the execution of the majority of buildings in this district occurred above the debris of the

Junta do comércio and *palmo de comércio* (or *craveiro avantajado*) were important for commerce (Santos, V.L. 1994, AM 5-6).

[68] The building in *Rua dos Fanqueiros* nos. 176-178 now accommodates two public elevators.

[69] This latter requirement may also underpin the recourse to pre-fabricated components (Mascarenhas, J. 2004, 173-174).

[70] The overview of the main historical phases of this convent and its architectural features is provided by M. Soromenho (DGEMN 2004, 116-123) and M.H.R.Santos (DGEMN 2004, 124-131).

[71] Among the 65 maps of the city drawn by the general Folque, maps nos. 43 and 51 include the regular boundaries of downtown Lisbon. This atlas was initially composed of 63 maps to which two maps of Belém parish (nos. 59-A, 59-B) were later included (CML 2000).

[72] Significant alterations to the natural site, such as excavating and refilling the ground, often followed the frequent post-seismic damage in Lisbon. However, the pre-1755 seismic responses were smaller and more sporadic in comparison to the comprehensive post-1755 activities, as underlined by Rossa: "Each of these episodes [i.e. previous post-earthquake reconstruction] caused major topographical and morphological changes, but the reconstruction responses were always of suturing, refilling, repair." *Pt*: "Cada um desses episódios [i.e. reconstruções pós-sismos] produzia alterações topo-morfológicas de monta, mas as respostas de reconstrução foram sempre de cerzidura, colmatação, reparo." (Rossa, W. 2015, 364-365)

ancient town, the ground level was intentionally altered in the eastern side of this area by excavation and earth removal, including the demolition of the Roman walls bounding the salting tanks (*cetariae*).[73]



Figure 4.13 – (top) topographical plan of Lisbon by Carlos Mardel (1755), Museu da Cidade de Lisboa; (bottom) map of blocks of Freguesia de São Nicolau, by Monteiro de Carvalho (from *Livro das plantas das freguesias de Lisboa*, plate no. 41, 1756-1768?)

[73] (Fernandes, L.M.M.; Mota, N.M.M. 2011, 17-18)

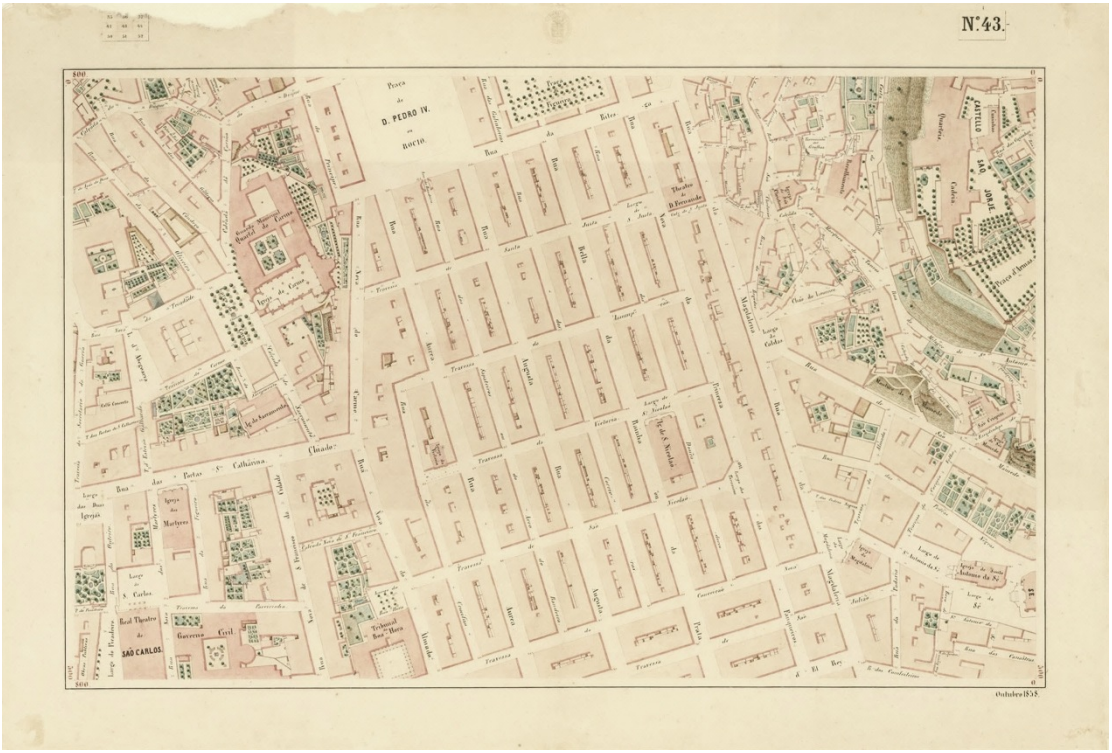


Figure 4.14 – Topographical plan of Lisbon from Folque's atlas, no. 43 (1858-10) (CML 2000)

The difference in elevation of the eastern area – the case study's location – is likely higher than it was in medieval times. As deduced from archaeological data in this area, the earlier profile of the hill was not as steep as it is currently between *Rua dos Fanqueiros* and *Rua da Madalena*.[74] Debris deposits were used to increase the sill levels in the lower area; areas of hillside were excavated to allow adequate floorspace for the new constructions there.

On steeply sloping streets, as in this case study, the execution of a mezzanine floor compensates for differences in elevation, providing uniform height across the facades. The stone doorjambs of the ground floor extend upward into the mezzanine; giant lesenes, introduced in Portugal by Terzi and arising from Serlio's lesson,[75] at the middle of the block also indicate variation of the street altimetry[76] where the alignment must be straightened.[77] Regardless of the presence of the mezzanine floors or giant pilasters of Tuscan style – as Duarte specifies[78] – as well as surface differences in colour or material, overall harmonization of the urban ensemble still persists.

The anatomy of the buildings reflects the urban space and vice versa: the dynamics of household life entwined with the echoes of a bustling commercial district (*Figure 4.15*). The street of this case study is indicated in the Decree Law of 5 November 1760 as *Rua Nova Princesa*, but today it is known as *Rua dos Fanqueiros*, having been renamed in 1910 following the overthrow of the monarchy. Traders, booksellers, and shops of cotton

[74] (Diogo, A.M.D.; Trindade, L. 2000) (Bugalhão, J. 2001)
[75] (França, J. A. 1987, 177)
[76] (Mascarenhas, J. 2004, 173-174)
[77] In one of the rare building plans reported in *Cartulário Pombalino*, no. 47 on *Rua da Cotovia*, the small open-fan-like volume is marked by a lesene, which interrupts the sequence of the identical doors on the ground floor (Viegas, Inês Morais (ed.) 2006).
[78] (DGEMN 2004, 76-87)

and linen were installed in this street.[79] As one of the main axis between two important public spaces – the squares *Figueira* and *Terreiro do Paço*[80] – *Rua dos Fanqueiros* embodied the liveliness and the dynamics of this district. Its importance in this rebuilt district can be deduced by the average economic value of its building facades. Different prices for lot frontage were established for each street of downtown Lisbon, depending on location, i.e. an increased value when overlooking a main street,[81] or when the plot was close to the river or to the *Rossio* or *Figueira* squares, or if placed in a building corner. The economic value of buildable plots was established according to a well-defined hierarchy, depending on the location of the plots both in the street and within each building.[82] Santos specifies that the maximum value was attributed to the front span of the building lots contiguous to *Rossio* square from 16,000 to 20,000 *réis*, whereas the minimum value of 7,000 *réis* was for the lots further from the river (i.e. *Rua Douradores*, *Rua dos Sapateiros*, and *Rua dos Correeiros*). As regards the other streets parallel to *Rua Augusta*, the buildings in *Rua Nova da Princesa* (*Rua dos Fanqueiros*) and *Rua da Madalena*, standing equally close to the river, were valued from 7,500 to 8,500 *réis*.[83]

[79] "Mercadores de Lançaria ou Fancaria, destinando-se os sobejos della se os houver, às lojas de quinquilharia".
[80] *Praça da Figueira* has been a fruit and vegetable market since 1775 (Santos, M.H.R. 2000, 80) and was also used for bullfighting, whereas *Terreiro do Paço* was a seafood market.
[81] *Rua Áurea*, *Rua Augusta*, and *Rua Nova d' El-Rei* (*Rua do Comércio*) were designed as the *noble streets*. *Rua da Prata* became the fourth important axis of the new district (Santos, M.H.R. 2000, 76).
[82] The economic value of these apartments decreased in each floor above the first (Madureira, N.L. 1992, 41).
[83] (Santos, M.H.R. 2014, 350)



Figure 4.15 – *Estabelecimento comercial A Confiança de Lisboa* in *Rua dos Fanqueiros* (photo by A.C. Lima, 1910s, AML, PT/AMLSB/CMLSBAH/PCSP/004/LIM/001073)

4.3.2 Tracing the main typological alterations over the centuries

As deduced by Lisbon payment reports, this multi-storey building was executed between 1780 and 1789.[84] It is a *singular plot*, a category to which 34% of *Pombalino* buildings belong,[85] indicating that the internal distribution is around a stairway that serves one apartment per floor and flanks the wall that divides this property from the adjacent plot (*Figure 4.16*). The elevation belongs to type B in França's definition: balconies on the first floor, but without any cornices separating it from the ground floor. Its openings are arranged in a 5 x 3 grid regularly aligned across the first four levels (ground floor, mezzanine, first, second, and third floors) and the upper floor, whose *varanda corrida* (long balcony)[86] is set on the simple cornice of the original volume built in the first phase. The execution of an extra floor above a continuous simple cornice was introduced in the *Pombalino* plots for increasing the rentable floor areas, as proposed – according to Ratton's account – by Manuel Caetano de Sousa (1742-1802).[87] The ratio between each opening and the wall is 1:1, the same *belle proportion* proposed by Augustin-Charles d'Aviler in the *Cours de Architecture* (1691).[88] Simple giant pilasters marked the main facade; the roof is bordered by high walls, whose use was mandatory in compliance with the 15 June 1759 decree of law, to prevent the fire from spreading (*Figure 4.17*).

Except for the ground floor, this simple layout is repeated in each plan and is characterised by a sequence of four timber frame walls parallel to the main street. There are no corridors: internal circulation is made from room to room, with a rear patio of less than six square meters. In addition to the main staircase, another small stairway compensates for the difference in elevation of the rear compartment of this building, which is offset by approximately 1.70 m. The windows of the patio of this rear portion are not aligned, resulting in the staggered layout of these facades (*Figures 4.18*, *4.19*).

For insight into the overlapping evidence of different requirements across time, some data on this building can be found in the dossiers collected in the Lisbon Municipal Archive (AML) regarding two periods:[89] 1905 to 1951 and 1961 to 2014 (*Appendix C.1.2*). The oldest document included in these municipal dossiers dates back to 24 August 1905. A set of works, which required municipal approval, was exempt from requirements for a project or for consultancy on health improvement; this included the replacement of two walls by iron beams, the substitution of a staircase,[90] the conversion of a window to a door, the installation of a urinal in the patio, as well as other unspecified internal and external repairs. More specific information is provided in a later authorization request of 27 January 1911 (*Appendix C.1.2.1*). The shop owner's request includes the oldest drawings of this case study collected in AML, i.e. a ground-floor plan with a portion of the main facade and an extract of the cross

[84] A comprehensive analysis of the archival dataset is carried out by Reis, Simões, and Rodrigues aimed at defining the pace of reconstruction work (seven phases from 1762 to 1834) in downtown Lisbon. Their research is based on the payment report from 1762 to 1840 (*Livros da Décima da Cidade*, divided by parishes and years and regarding all properties, salaries, and borrowed capital), whose importance is also outlined by Mascarenhas (DGEMN 2004, 58-65). Tax records provide evidence by which to date buildings since owners were asked to pay an annual tax from the time when each building was executed.

[85] (Mascarenhas, J. 1996, 167)

[86] From the 1780 the mansard roof on the fourth floor of *Pombalino* buildings was often replaced with a new storey, similar to the existing ones. Their continuous balconies were divided by *grades de risco* to give some privacy between different tenants.

[87] (França, J. A. 1987, 176)

[88] French influence in *Pombalino* grammar is expressed in the facade layout, roof, and the systematic use of wood components, as stated by Duarte (DGEMN 2004, 76-87).

[89] AML, PO 38639, vol.1&2. The rehabilitation works carried out from 2014 to 2016 are not still available in the municipal archive.

[90] It can be assumed this was a ladder at the rear of the plot.

section of the building. These drawings offer some useful data on the user's requirements in this epoch. The project on the ground floor aimed to split the patio area into two parts (one bordered by a new wall and protected by a glass roof),[91] to provide a new road-level access to this patio (i.e. making the shop independent from the stairwell by a window-to-door replacement) and to the mezzanine floor (with a new door in the timber frame wall supporting the staircase), and to install a toilet and chimney in a roofed patio (*B* in *Figure 4.15*). Moreover, following this owner's request, this building plot was divided into two parts, the first portion including only the staircase serving all floors and a long corridor connecting the patio to an L-shaped room. The second part of the ground floor is a large undivided space. A part of the rear patio has been absorbed due to the shop owner requirements since 1934: this tendency to occupy tiny collective area results from reasonable yet questionable habits, similar in the majority of other surrounding building plots. Minor alterations of the main facade include introduction of a refined metallic roof in neo-classical style (in 1915, *Appendix C.1.2.2*) for protecting the pedestrian walk (of 1.50 m in width),[92] plastering of the facade (garnet-coloured in 1930 – later replaced by light grey-coloured in 1938),[93] and installation of a carmaker's advertising sign (in 1934).[94]

The building layout remained unchanged until the 1950s with the slight exceptions of roof repair works in 1939 and other maintenance works,[95] including one obliged by the authority in the aftermath of a 1948 fire on the second floor[96] – a common type of occurrence due to the storage of flammable materials (as shown in another building plot in *Rua da Madalena*, *Figure 4.19*).

The installation of a warehouse and office of an electrical supply company (*Primax*) involved several alterations in the mezzanine and first floor, especially in the interior rear space, occupied by bathrooms, a kitchen, the staircase, and the lift.[97] In addition, a sign was affixed in 1951,[98] replacing the former advertising sign, and the metallic roof was removed.

As a consequence of the 1950s works, this typical layout based on a single staircase was altered.[99] In fact, the store occupying the ground floor, mezzanine, and first floor turned into a compartment with an independent access and an additional staircase on the rear facade. In order to execute this staircase, parts of a masonry wall were demolished (approximately 1.00 x 3.60 m on the first floor and 1.00 x 1.90 m on the mezzanine) and reinforced by metal beams.

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[91] Three years later, the owner requested to replace it with a corrugated roofing sheet with ventilation equipment (*B* in *Figure 4.15*), in order to adapt the patio to a horse stable (AML, PO 38639, 2041, folha 1). While the alteration of the use of the common external area to an animal shelter was reasonably rejected in compliance with the law of 22 July 1905, other owner's requests were accepted.

[92] Supported by three metal profiles for a length of 8.25 m, this roofing included a glass structure with a gutter towards the facade surface. Its execution was accepted on 3 July 1915 (AML, PO 38639, 3826/15, folhas 2,3).

[93] Approved on 22 July 1930, in compliance with the article no. 16 of *Regulamento das Condições Estéticas dos Edifícios Urbanos* (Aesthetic rules for urban buildings). In addition to the indication for the facade's colour dated back on 30 November 1938, the facade in the rear should be white-plastered, whereas the shutters, doors, eaves in dark-green bottle.

[94] Requested on 16 August 1934 (AM, PO 38639, 4213/34, folha 2).

[95] Interior works at ground-floor and first floor, substitution of window frames (1946).

[96]"(...) several wooden partitions completely burned and all the wooden fittings were cracked in the compartment affected by the fire." *Pt*: "(...) arderam totalmente diversas divisórias de madeira e ficaram parcialmente crestadas todas as guarnições, também de madeira do compartimento atingido"(AML, PO 38639, 59518/38, folha n.1).

[97] AML, PO 38639, 41346/1950, folhas 1, 2, 3

[98] The permission to affix the *Primax* sign surmounted by a clock dial was requested on 20 November 1950, accepted a few days later (4 December 1950), and executed the year after.

[99] However, a former wooden staircase for the ground floor and the mezzanine already existed, whose project was not declared, executed after 1911 and prior to the 1950 (AML, PO 38639, 41340, folhas 2,13).

Similarly to most *Pombalino* buildings, different activities coexist in this multi-storey building: (i) a bootblack on the ground floor (no.114) – as testified by tax payments from 1929 to 1935 and by the 1959 request of permission to paint the interior and front door;[100] (ii) shop and storage of electric materials on the ground floor (nos.112-110) and mezzanine; (iii) rented apartments in the upper floors – as can be deduced by a tenant complaint of water infiltration in 1938.[101] Besides this information, it can be also deduced that there was a single owner – Mrs Virginia Julia de Conceição Reis Carmona – from the ground floor (no. 114) to the apartment of the second floor.

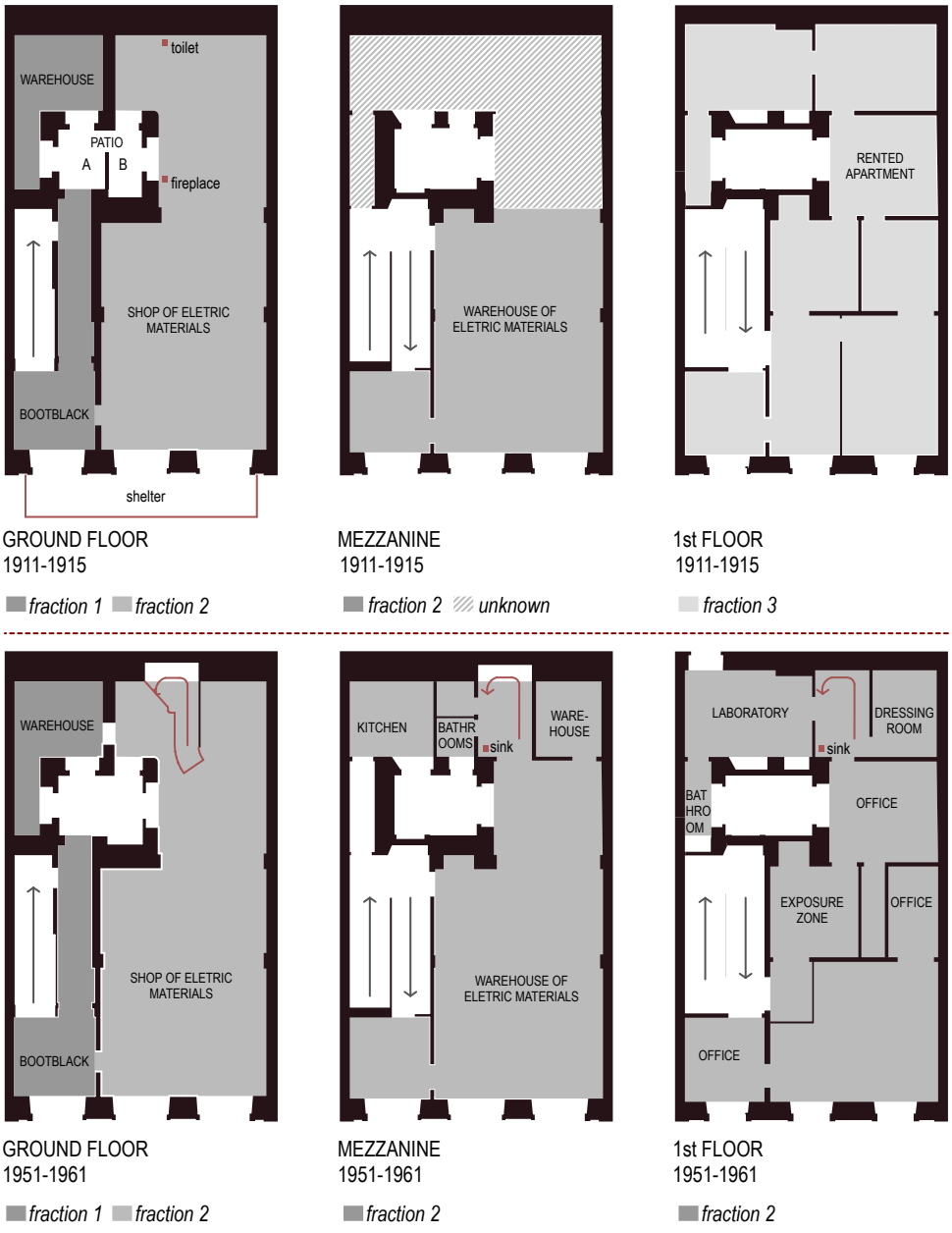


Figure 4.16 – Diachronic distribution layout of the case study 1 (© S. Stellacci)

[100] AML, PO 38639, 4/0/366/43, folha 3; AML, PO 3863916037/59, folha 1
[101] AML, PO 38639, 59518/38, folha 1

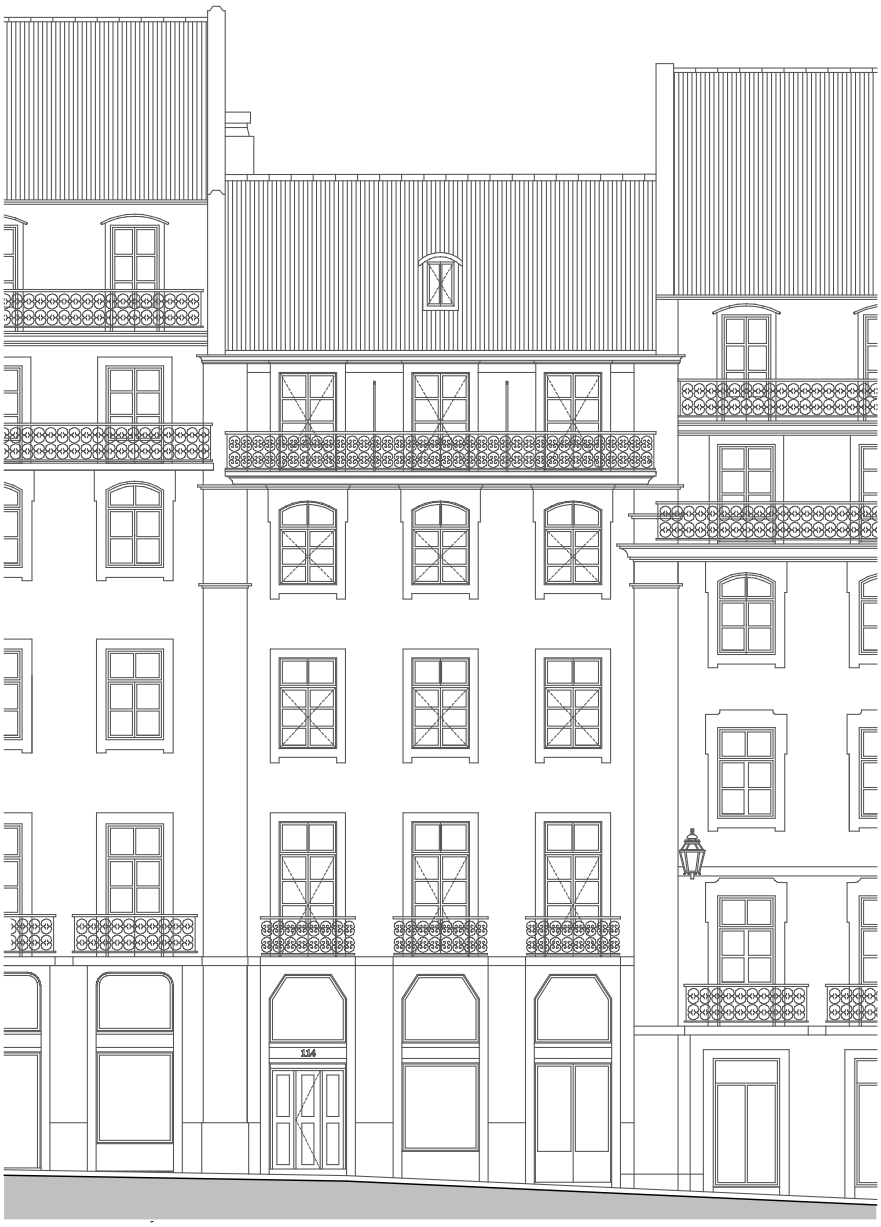


Figure 4.17 – Main facade in *Rua dos Fanqueiros* nos. 110-114, Lisbon (© S. Stellacci)

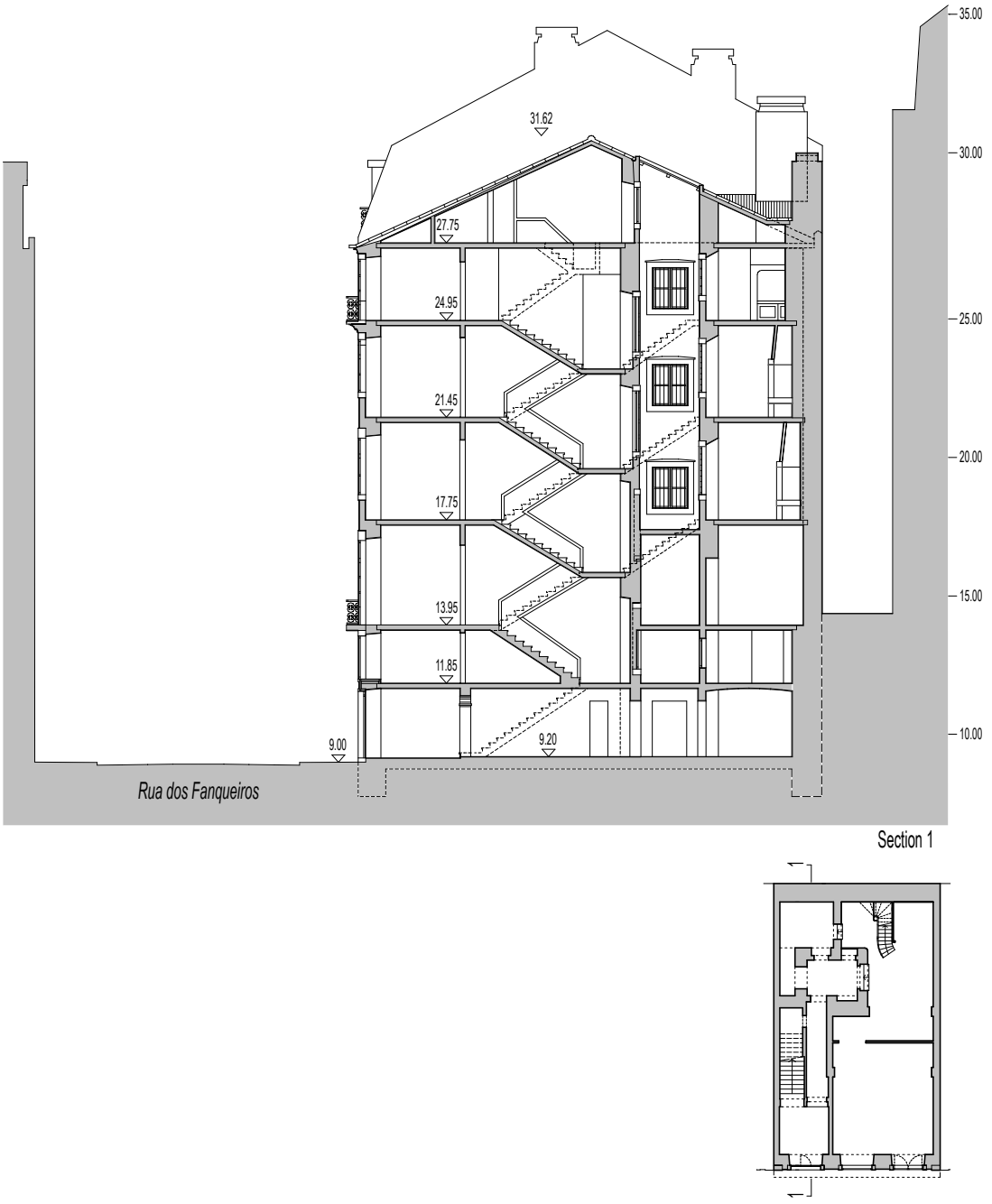


Figure 4.18 – Longitudinal section of the case study 1 (© S. Stellacci)

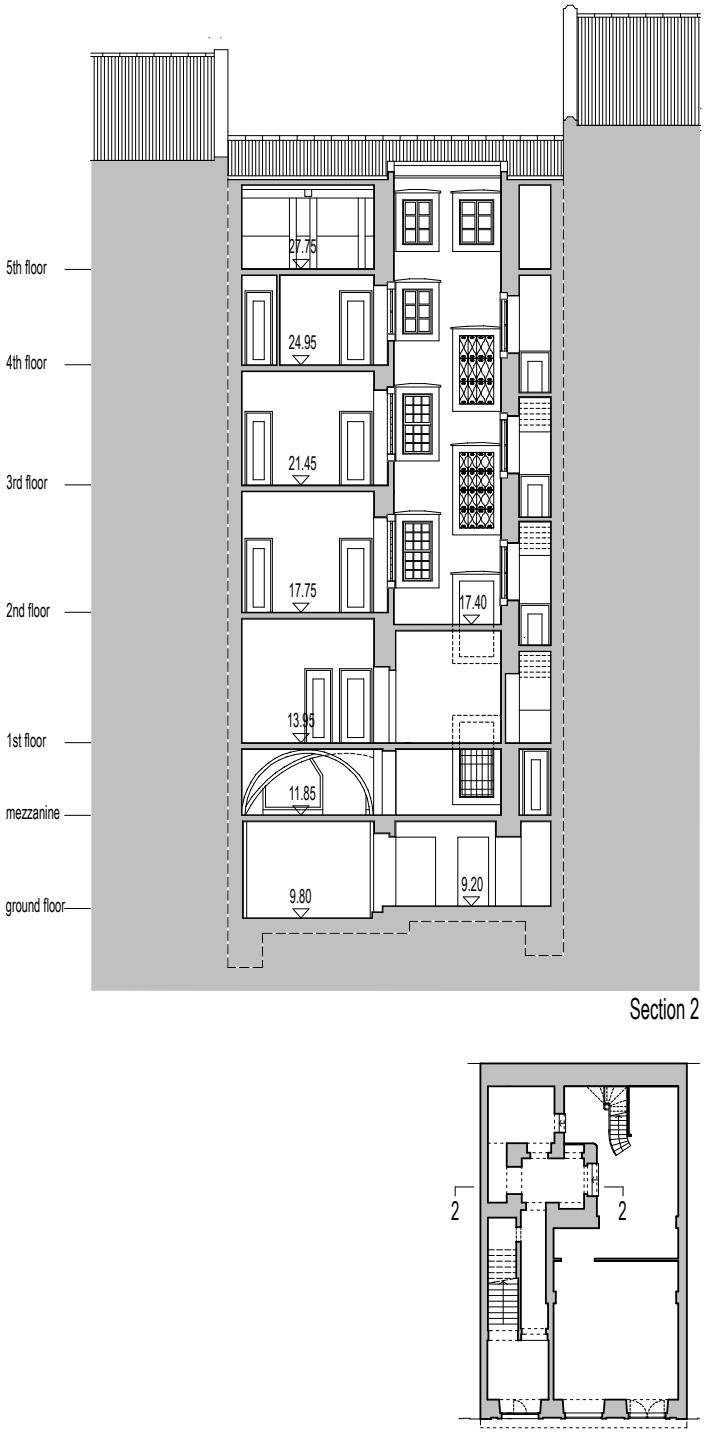


Figure 4.19 – Cross section of the case study 1 (© S. Stellacci)



Figure 4.20 – Timber frame wall revealed due to the fire in the building in *Rua da Madalena*, Lisbon (photo by P. Guedes, 1907, PT/AMLSB/CMLSBAH/PCSP/004/PAG/000256)

4.3.3 Construction system and material characterisation

When the survey of this case study was carried out by the author in 2014,[102] the wall and ceiling finishing layers (mortar and plaster) had already been completely removed by builders in order to check the different structural materials and their condition for a rehabilitation project in progress.

4.3.3.1 Vertical structure

Three principal types of wall are observed in this case study (*Figure 4.21*, *Appendix C.1.3.1*):

- external walls in rubble stone masonry, primarily of limestone and reinforced by a timber framework on the inner face, around the openings at every level (0.90 - 1.00 m of thickness, generally decreasing in the upper floor to 0.60 - 0.70 m);
- plot partitions (*paredes meeiras*) in rubble stone masonry of limestone bounded by aerial lime-based mortars (probably 0.70 m of thickness);
- internal load-bearing walls in half-timbered frames (TFW) above the ground floor, i.e. wooden skeleton filled by heterogeneous material covered by plenty of lime mortar (0.16 - 0.20 m of thickness).

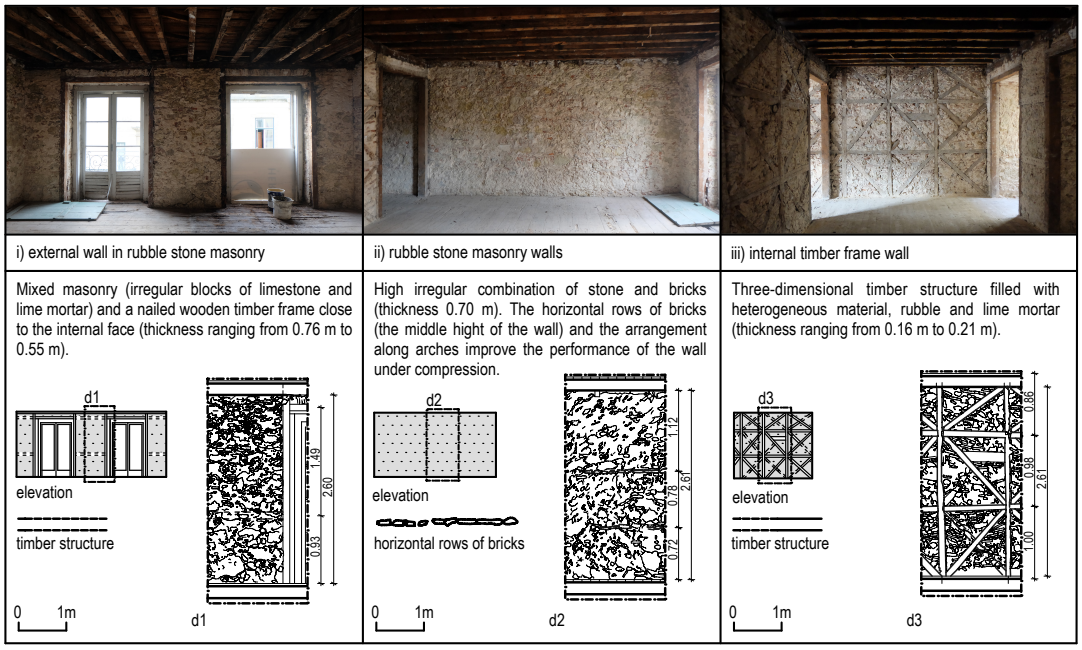


Figure 4.21 – Three types of vertical structure in the case study 1 (© S. Stellacci)

In addition, thinner partition walls (0.10 m of thickness) known as *tabiques* were executed flanking the staircases of the fourth and attic floors. They are composed of wooden planks covered by other timber components and plastered by earth-based materials.[103]

[102] This survey, based on drawings (plans and elevations) by the architect Santa Rita, was carried out while the works were already in progress.

[103] The *tabique* walls were not executed directly on the top of the floors, but connected to the floor structure through the *frechal* (wooden beam) and lateral locked to the other components of the *gaiola* (Leitão, L.A. 1896, 298-301) (Santos, V.L. 1994, II.4.1.32). These partitions have been considered for a long time of negligible structural importance, but recent experiments carried out by Rebelo and other scholars from the University of

This analysis focuses on timber frame walls (TFW), which are divided into three vertical modules of Saint Andrew's crosses on all floors, with the exception of the mezzanine in which the walls are divided into two modules due to the lower height of this level (1.93 m). This subdivision and height do not comply with the rule defined after the earthquake and described by Mascarenhas that established three of these vertical modules for the first floor and two modules on each floor above (16 *palmos*, corresponding to 3.50 m for the ground floor and the first floor).[104]

The vertical posts (*prumos*), placed approximately at a distance of 0.90 m, reach a height of more than one floor. The structural continuity of the vertical posts provides greater mechanical strength for the structure. The posts have a variable cross section. The cross section of the vertical posts of the skeleton, which frames the openings (*Figure 4.21*, type i), is approximately of 8 x 14 cm. In the interior wall (type iii), they are progressively smaller from the first floor to the upper floors (from 0.15 x 0.30 m to 0.10 x 0.16 m). The infill of the triangular voids is composed of bricks and irregular stones with lime mortar. In some cases, such as in the mezzanine, the horizontal timber elements are longer than the dimension of the module, and support the diagonal and vertical elements. The infill in aggregate, stones, and bricks greatly varies from frame to frame within the same wall. The many differences in type of infill can be observed between the fourth and the lower floors, since the number of bricks and the regularity with which they are laid are greater in the fourth floor (*Appendix C.1.4*).

The connections between the timber frame walls (*frontal tecido*) and the masonry walls, which delimitate the patio or the contiguous property, are made by inserting the timber members into the masonry wall, accordingly to the detail published by Leitão (1896). Leitão recommends placing the diagonal members (e*scoras* indicated with *e* in *Figure 4.22*, left), far from the connection points between the horizontal members and the vertical posts (*m* and *n*), stating that the vertical post should provide the necessary strength to avoid their bending.[105]

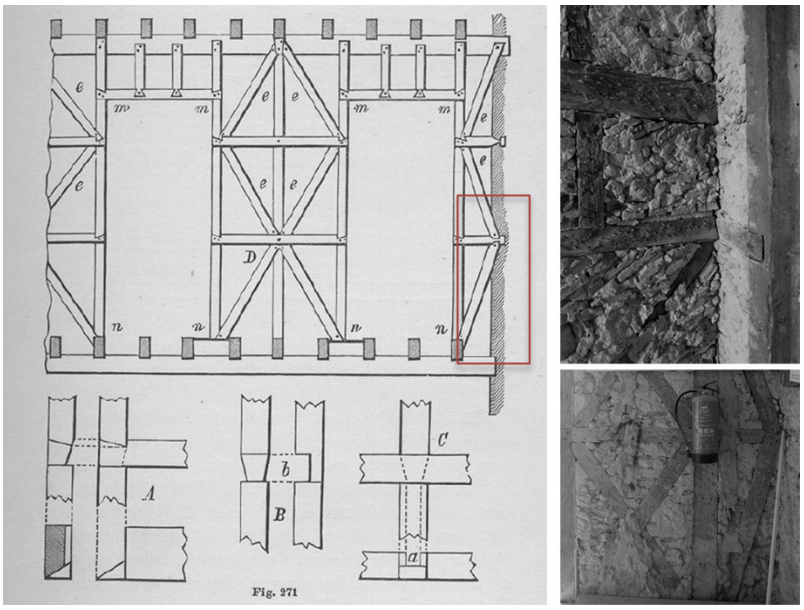


Figure 4.22 – Connection of timber frame wall (*frontal tecido*) to rubble stone masonry walls (Leitão, L.A. 1896, 297) and photos of the case study 1 (© S. Stellacci)

Porto (FEUP) have confirmed that these walls contribute to structural stability due to their good mechanical performance under vertical forces (Cruz, et al. 2016, 437-446). See *Chapter 2*, *section 2.3.1* and *Figure 2.14*.

[104] (Silva, R.H. 1997, 83)

[105] (Leitão, L.A. 1896, 296-297)

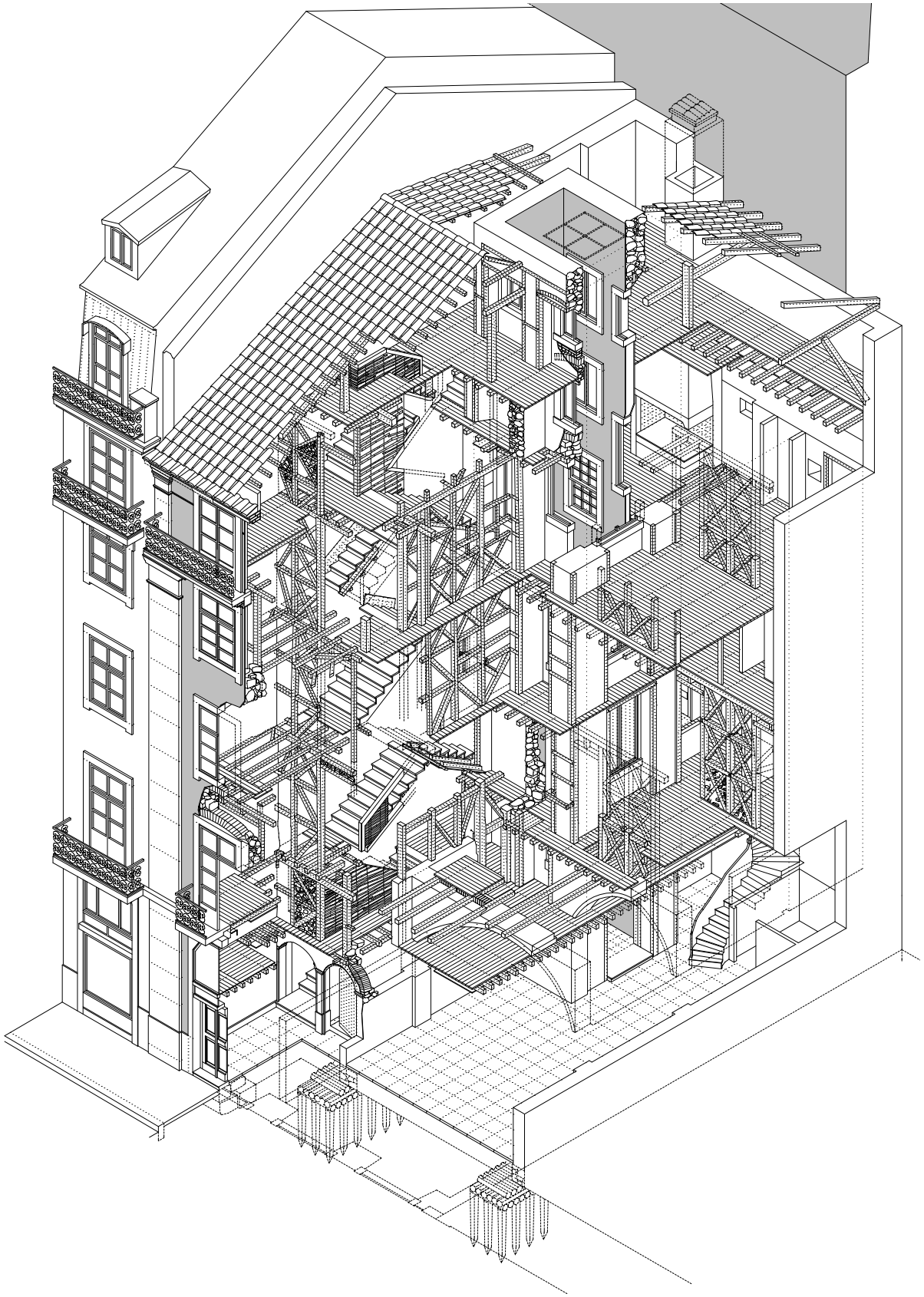


Figure 4.23 – *Pombalino* case study: Isometric view (© S. Stellacci)

In some cases, the bricks are arranged diagonally, while the stones are placed horizontally (*Figure 4.24*). The inclined position of the bricks, visible on the left of *Figure 4.24* (TFW1) causes a decrease in friction under horizontal forces. In other timber frame walls in the mezzanine (TFW2), a predominance of lime-mortar rather than masonry stones or bricks can be observed.

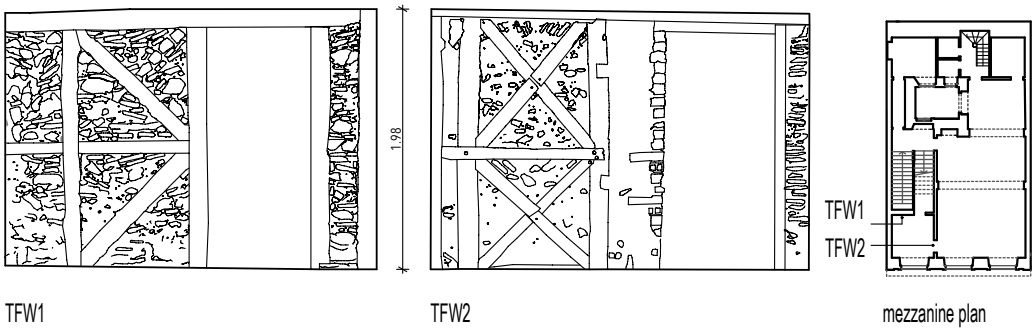


Figure 4.24 – Two timber frame walls (type iii) in the mezzanine floor (© S. Stellacci)

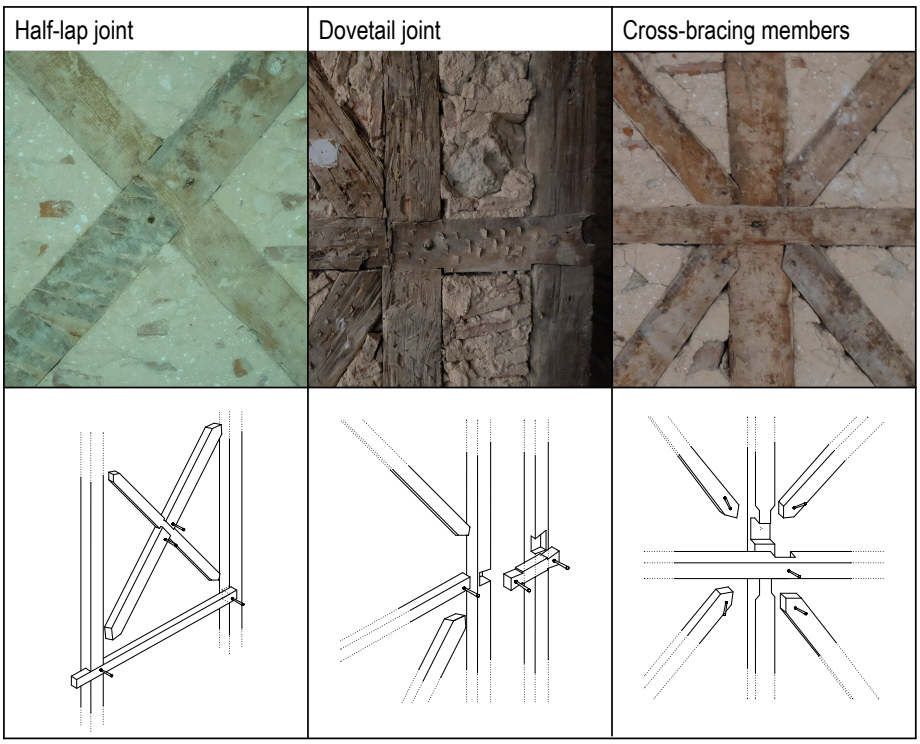


Figure 4.25 – Carpentry joints of timber frame walls in the case study 1(© S. Stellacci)

The timber elements are notched or connected by rounded head nails or iron ties. Half-lap joints are frequently used, adapted *in situ* and fixed by one or two nails or without any nails (*Figure 4.25*). To prevent a decrease in mechanical strength and to reduce the time of execution, diagonals uprights are often juxtaposed (*Figure 4.26*).

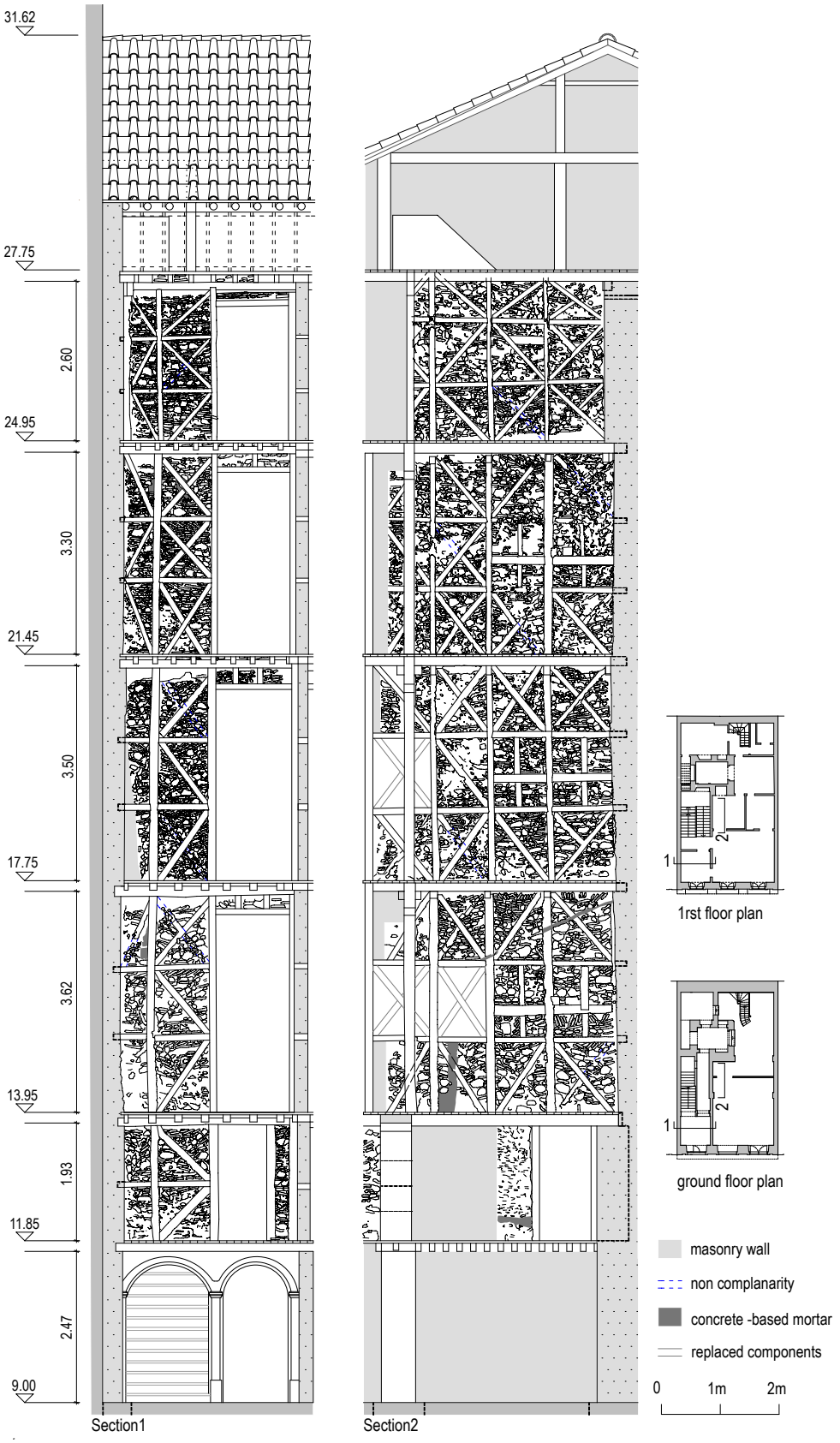


Figure 4.26 – Extracts of sections of the case study 1 (© S. Stellacci)

4.3.3.2 Roof structure

Due to the small dimensions of this plot, a simpler roof structure can be found in this type of building: a gable roof whose eave is parallel to the main street, *Rua dos Fanqueiros*, and supported by struts (*Figure 4.27*).[106] Clear evidence of repair works following a fire was observed in this roof (*Appendix C.1.4*, *Photograph no. 33*). Two rows of tree trunks (approximately cross section 16 x 16 cm) support the roof structure, connected or juxtaposed with each (replaced) collar tie that stiffens the rafters. Two trunks for each side, orthogonal to the main street, are stuck into the rubble masonry to buttress the structure. No timber frame walls or partitions were executed on this floor. Due to its sloping ceiling, the top floor of this building is not habitable across its entire dimensions (the average height is less than two meters).

In addition to the large windows on the thick masonry facing the patio, natural ventilation and light are provided by a tiny dormer, aligned to the center of the facade, and the skylight over the patio (*Figures 4.23* and *4.27*, top).



Figure 4.27 – Underpurlin, rafters, struts, and dormer window of the roof-space of the case study 1(© S. Stellacci)

[106] Other types of roof structures in *Pombalino* buildings are described in terms of construction system and formal influences by Mascarenhas and Duarte respectively, among many other scholars (Santos, V.L. 1994, II.4.1.43-48) (Mascarenhas, J. 2004, 102-110) (DGEMN 2004, 76-87).

4.4 Case study 2: the Bishop's Palace in Mileto

This selected case study represents the most important palace of the first phase of Mileto's reconstruction after the 1783 earthquake for its architectural and construction features. A convergence of Baroque legacy and Neoclassical language, it imposes itself upon all the rebuilt town as an expression of timeless ecclesiastic authority. An isolated compact volume, bounded by the main street *Via Duomo* (*Dome Street* whose two ends are bounded by the cathedral and the church of *Saint Angelo*), it cuts the planned double-size square, around which the original urban layout was conceived, into two segments.

4.4.1 Typological and architectural analyses

The palace was a seminary and seat of the bishopric, built in 1784 and executed in two stages,[107] although these construction phases are not identifiable by on-site or archival evidence. The works were committed and financed by the bishop Minutolo (1792-1824), paused, and resumed after a decade, carried out by the bishop Mincione (1847-1882) until 1795 (*Figure 4.28*).

Beyond this brief chronotaxis, more detailed information was not found from its early splendour until the overthrow of the 1799 government, when this palace – similarly to other buildings of the city – served as lodging for foreign soldiers. Friendly relationships grew between the French soldiers and the townsmen, as testified in the local chronicle; this palace hosted numerous meetings with prelates and judges, organised by Ruffolo.[108] Absorbed by a spirit of cultural renewal, the recovery of old marble monuments was undertaken. Mileto was the scene of French military operations against brigands[109] until Garibaldi's landing (27 August 1860).

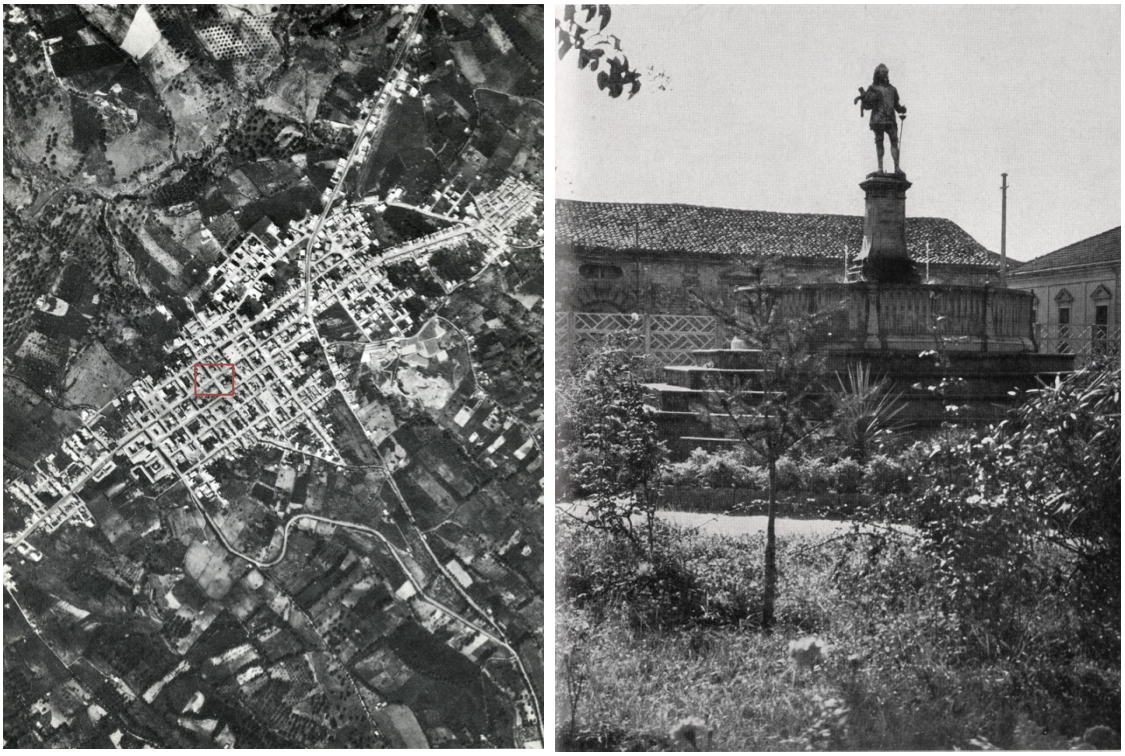


Figure 4.28 – Aerial photograph of Mileto (left) (AA.VV. 1982, 24); photo of the main facade of Bishop's Palace viewed from the central square (right) (Pata, F. 1966)

[107] (AA.VV. 1982)
[108] (Taccone-Gallucci, D. 1881, 36)
[109] (AA.VV. 1982, 23)

The layout of the palace is characterised by a sober architectural composition of Campanian influence.[110] Covered by a slightly inclined roof, the lengthy extension of the north facade overlooking the main square exceeds its other dimensions. Its facades are characterised by a regular sequence of openings above the high ashlar plinth (*Figure 4.29*). Giant lesenes, simple in the central spans and coupled as they get closer to the corners, [111] provide a rhythm to the surface and frame the rectangular windows. The variation of the rhythm in becoming denser from the entrance to the lateral sides slightly enlivens the facade. Alternating pointed and curved pediments frame each opening of the ground floor (*Figures 4.30*, *4.31*, *4.32*).

Similarly to other coeval palaces of the rebuilt towns, the entrance is clearly signaled by the arched front door to which the symmetric interior staircase corresponds.[112] The portal is made of ashlar blocks with convex sides and rounded corners. This feature is similar to other palaces in the city (e.g. Taccone-Gallucci Palace, Naccari and Romano houses), although it does not include their alternating rows of diamond-pointed granite stones. Despite its regular layout, the plan is asymmetric and not centered on the mentioned square. In fact, the main entrance is not central in its elevation and the first three bays are separated by a sequence of two lesenes, while the layout in the other spans is marked by a pair of lesenes originally characterized by thick flutes, as can be deduced from some fragments *in situ* (*Figure 4.30*).

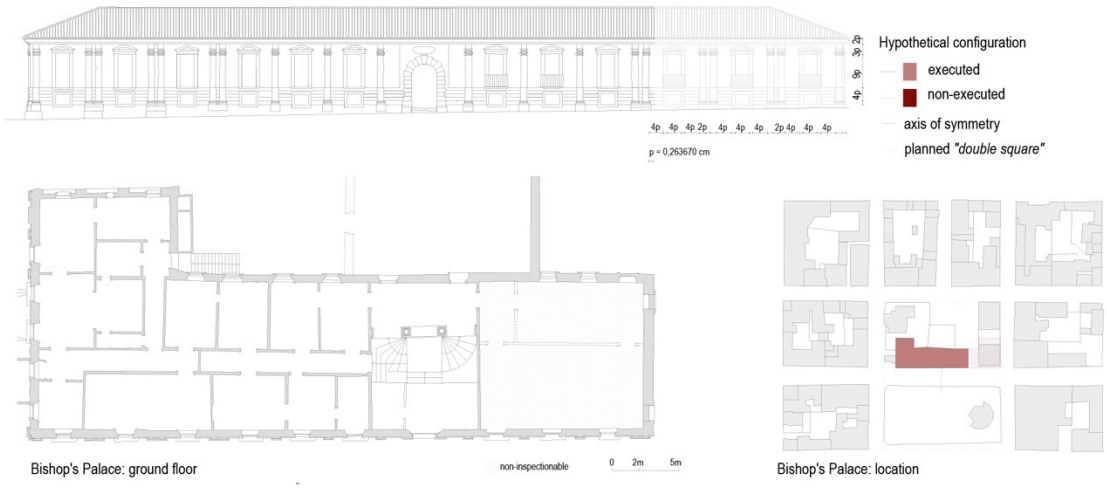


Figure 4.29 – Hypothetical *versus* executed configuration (© S. Stellacci)

The unrealized portions of this palace, which would have balanced the whole layout, include three openings framed between three pairs of lesenes. The ratio between the openings and the walls is 1:3.

The interior layout is simple, arranged along a sequence of two parallel spaces separated by a long corridor without windows. The tripartite staircase at the hall entrance is characterised by large flights and framed by a small loggia that divides the entrance space symmetrically. Its finishings have been lost along the centuries, and its bare state today stands in contrast to the impressive dimensions of its space. The depth of the staircase corresponds exactly to the depth of the adjacent room. The author of this thesis suggests that this was likely used as *cubitum salutatorium* (although this is not valided by references).

[110] (AA.VV. 1982) (Bardeschi, M.D. 2010)
[111] Sequences of giant lesenes are also observable in other aristocratic palaces, e.g. in Polistena, in *Via Vittorio Emanuele II* (Maretto, P. 1975, 100) and the palace in Seminara (Maretto, P. 1975, 146).
[112] e.g. Prince Palace on *Corso Italia* at Cittanova

A brief comment on the main staircase can be useful to understand the model possibly followed in this epoch. Its location and configuration is in compliance with the principles stated by Morris about its position in the building:

> "Stair-cases are the next Part of internal Designing, and require Judgment in the Disposal; they must be so placed as to be well illuminated, contiguous to the Center of the Building, or else more than one in Number; and so placed, that each Room may be near them, and have an easy Access to them, without incommoding any of the rest of the Rooms: Their *Going* should be large, the *Tread* broad, and the Rise easy for principal Stairs (…)".[113]

The ashlar plinth reaches the sill of the ground floor's windows, which are framed by sandstone jambs. The doorway is enhanced above the keystone by a stretched window with curved sides and at the bases of the lesenes with a floral motif. Brick cornices, window jambs, and simple capitals enrich the external walls. The sandstone, the elegant portal, and some marble bases of lesenes (composed of the upper torus, collar, scotia, and lower torus) were recovered from ruins of the old Mileto, as *spolia in se*.[114] As visible in many post-1783 buildings in the city, the reuse of materials and ornaments from the old towns was very common for economic and practical reasons. In this case, two hypotheses can be formulated regarding the presence of different materials for the same components, i.e. the bases of single or couple lesenes that enrich the external walls. The first, which is more plausible, supposes that original marble bases on granite pedestals were salvaged from an old structure (probably from the Norman epoch), with additional bases built to match, but in humbler materials. The second hypothesis is that the old marble stones were employed and reshaped according to the 1784 layout. The difference in material was probably concealed by a finishing layer. If the first hypothesis is correct, the dimension and composition of the old blocks became the rule for the new building. The wooden lintels on top of the window frames are cut to fit coplanar to the wall surface (*Figure 4.30*).



Figure 4.30 – Detail of east elevation: wooden lintel of window (© S. Stellacci)

[113] (Morris, R. 1734, 110)

[114] Introduced by Marcus Tullius Cicero in reference to the goods confiscated after a battle, the term *spolia* is distinguished by Brilliant into *spolia in se* (an ancient reused building) and *spolia in re* (a new building that re-purposed ancient iconography) (Chiesa, G.S. 2012).

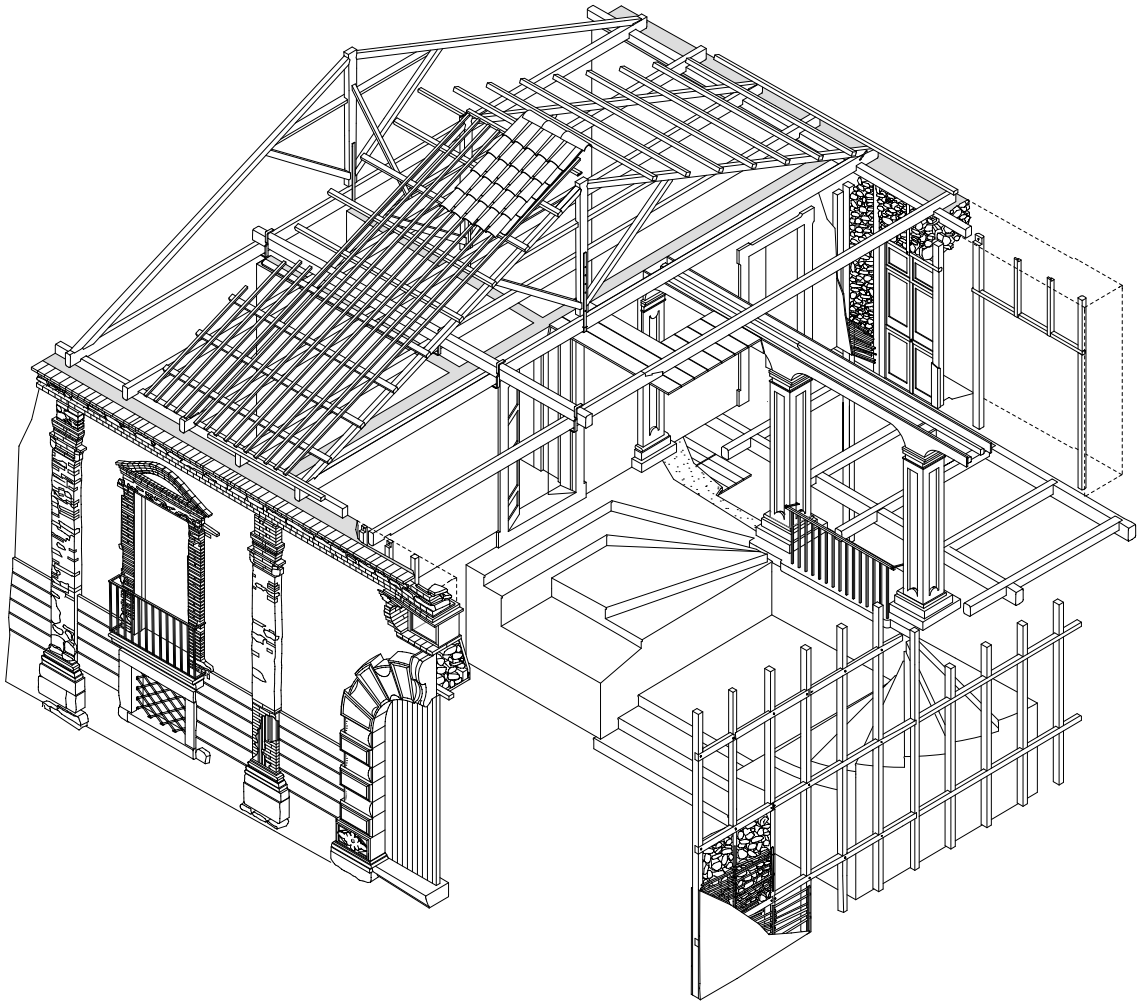


Figure 4.31 – *Borbone* case study: Isometric view of the loggia (© S. Stellacci)



Figure 4.32 – Detail of lesenes with volutes made by single bricks (left) and pointed pediment (right) (© S. Stellacci)



Figure 4.33 – Bases of single or double lesenes made of marble from the old Mileto (top); granite blocks post-1783 (bottom) (© S. Stellacci)

Unlike the north facade, which remains unchanged in its main layout,[115] the south and west facades have recently been modified. As a consequence of its new function as a warehouse on the ground floor, a wide opening and a U-shaped concrete ramp were executed due to the height difference between the ground floor and street level. Additional alterations include a staircase on the southern facade, the filling of the openings against intrusions, and the execution of a partition transversal to the corridor that today impedes access from the main entrance.

[115] However, all the openings were filled with hollow bricks and cement-based mortar.

4.4.2 Construction system and material characterisation

The Bishop's Palace is a relevant example of *sistema baraccato*, whose structural reliability was tested in the 1908 earthquake, when only the facade overlooking *Via Seminario* was slightly damaged.[116] Its original seismic resistance is due to its height limitation, its regular layout, and the interlocking of its structural components.[117] Each timber framework on the inner side of the external walls is connected to the floor and to the roof structure by lap joints, while the infill of the timber framework is composed of irregular stone rubble.

4.4.2.1 Vertical structure

Due to its state of complete disrepair, the skeleton of this building is visible; the vertical structure can be distinguished into these three types (*Figure 4.34*):

- perimeter wall, composed of stonework reinforced by a timber skeleton on the inner side which is connected to the floor and roof structures by carved or nailed carpentry joints (thickness from 0.51 m to 0.55 m);
- inner wall (type A), along the east-west axis, composed of vertical posts covered by reed mats (*incannucciato* technique, wattle) (thickness from 0.15 m to 0.20 m);
- inner wall (type B), along the north-south axis, composed of vertical posts onto which timber planks are nailed (thickness from 0.18 m to 0.20 m);



(i) external timber-framed wall	(ii) internal wall (type A)	(iii) internal wall (type B)

Figure 4.34 – Three types of wall in the case study 2 (© S. Stellacci)

(i) The masonry blocks are mixed, composed of heterogeneous materials – terracotta, marble, and granite. Its stone is classified as *calcilitute*; the mortar is composed of lime and quartzose-granitic aggregates; the wood species is Calabrian Chestnut (*Castana sativa Mill.*).[118] Some transverse bond-stones (*diatoni*) are placed in the orthogonal plane of the wall to engage it and prevent shearing forces. On the inner surface, a timber-framed system is nailed and carved with accuracy, but lacks X-bracing. The thickness of the external wall ranges from approximately 0.51 m to 0.55 m, thus less than provided in the *Borbone* legislative regulations (1784), i.e. two-

[116] Indicated as *baracca vescovile* in the map of surveyed damage of Mileto's buildings provided by Baratta (Baratta, M. 1908, 187). See *Chapter 3*, *section 3.5.4*

[117] This palace has been abandoned for many years; the drawings included in this work were illustrated in March 2015 by the author of this thesis, following the on-site survey coordinated by professors Michele Zampilli, Francesca Geremia, and Ginevra Salerno (University of Roma 3, Rome) and Dr. Nicola Ruggieri. These drawings are based on the previous survey coordinated by Prof. Andrea Lonetti (University of Calabria).

[118] A petrographic analysis was carried out within the Earth Science Department of the University of Calabria, and the microscopic analysis of the wood specimen by CNR-Ivalsa (Ruggieri, N.; Zinno, R. 2015).

and-a-half palms (approximately 0.65 m).[119] In addition to the timber framework on the inner face of this wall, reinforcement of the stone structure using wooden beams – irregular and generally with bark, known as *radiciamenti* (defined by Alberti as *legamenti*) – can also be encountered on the external side, especially above the openings. These members are able to distribute vertical loads from other structural elements. In order to ensure greater stability, some timber uprights, placed with a span of approximately 3.60 m (corresponding to one interior compartment) reach the lower level (*Figure 4.35*). The vertical posts flank the stone masonry, with no connections or carvings, whereas the bonding is guaranteed at the both ends, to the floor and roof structures (*Figures 4.36*).

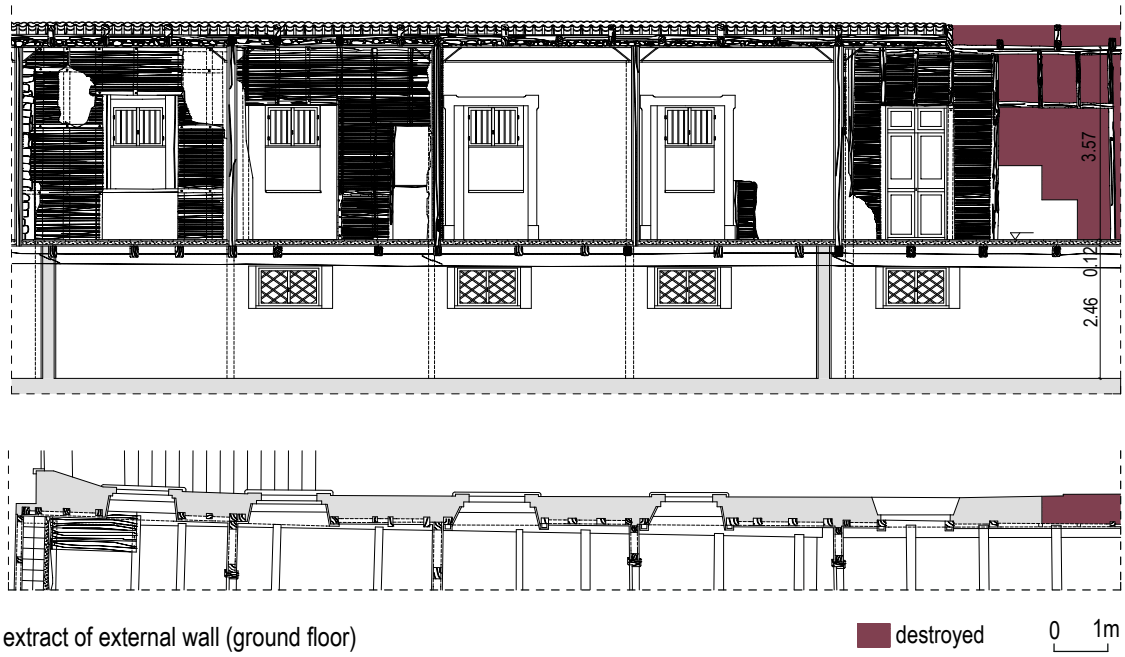
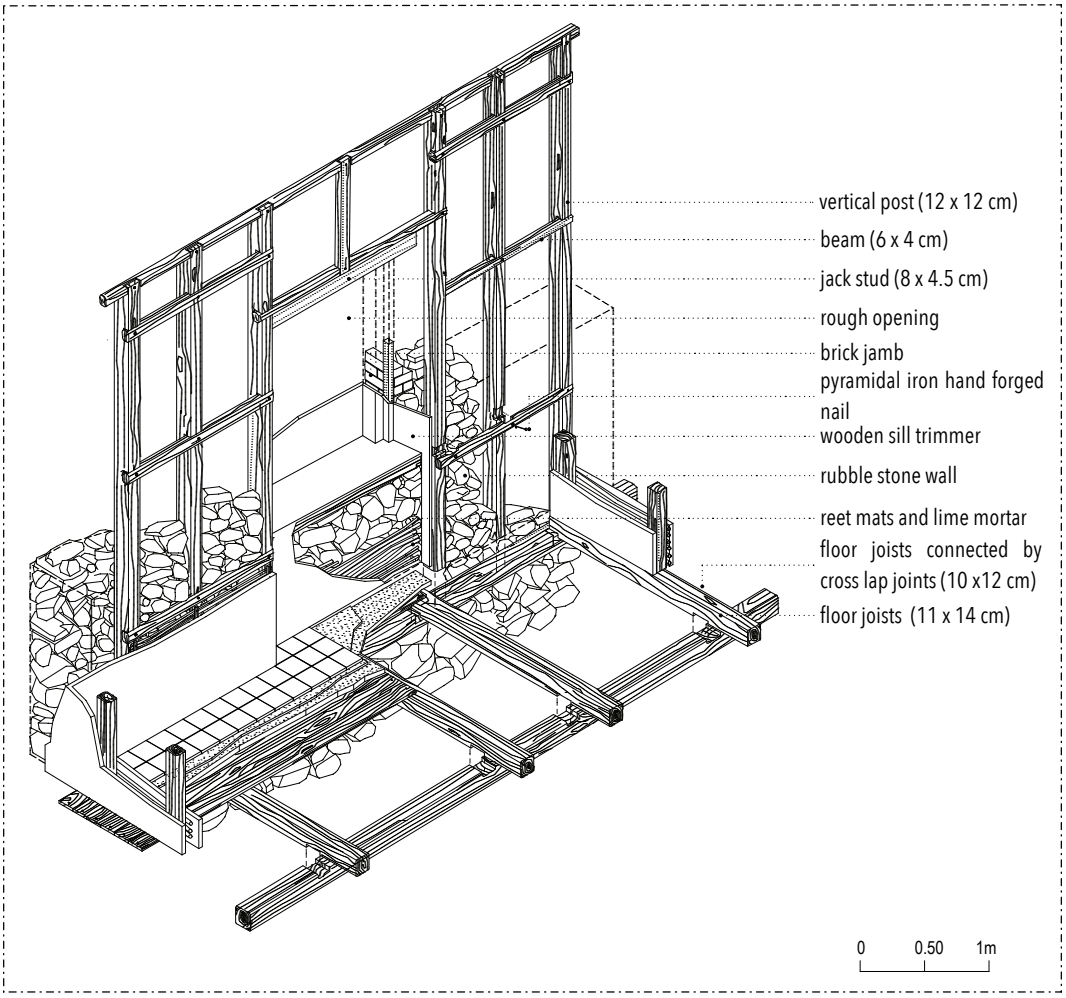


Figure 4.35 – Plan and elevation of external wall of the south elevation (type i) (© S. Stellacci)

A portion of this type of wall (*Figure 4.36*) was replicated as a full-scale specimen for quasi-static cyclic tests according to UNI EN 12512:2003, i.e. cycle testing of joints (made with mechanical fasteners) in September 2013. The tests were performed without infill and with infill up to a displacement of 80 mm.[120]

[119] (Aricò, N.; Milella, O. 1984)
[120] (Ruggieri, N.; Zinno, R. 2015)



Figures 4.36 – Isometric view of south external wall (type i) (© S. Stellacci)

The wall was originally covered by a thick plaster (3 cm) directly applied to the surface on both sides of the external masonry or on internal side with wattle and daub (*incannucciata* or *in cannucciato*). Evidence of the original pinkish plaster can be found in some points of the ashlar (*Figure 4.37*).



Figure 4.37 – Evidence of original pinkish plaster on external wall (© S. Stellacci)

Evidence from this case study sheds light on the traditional Calabrian system and confutes the

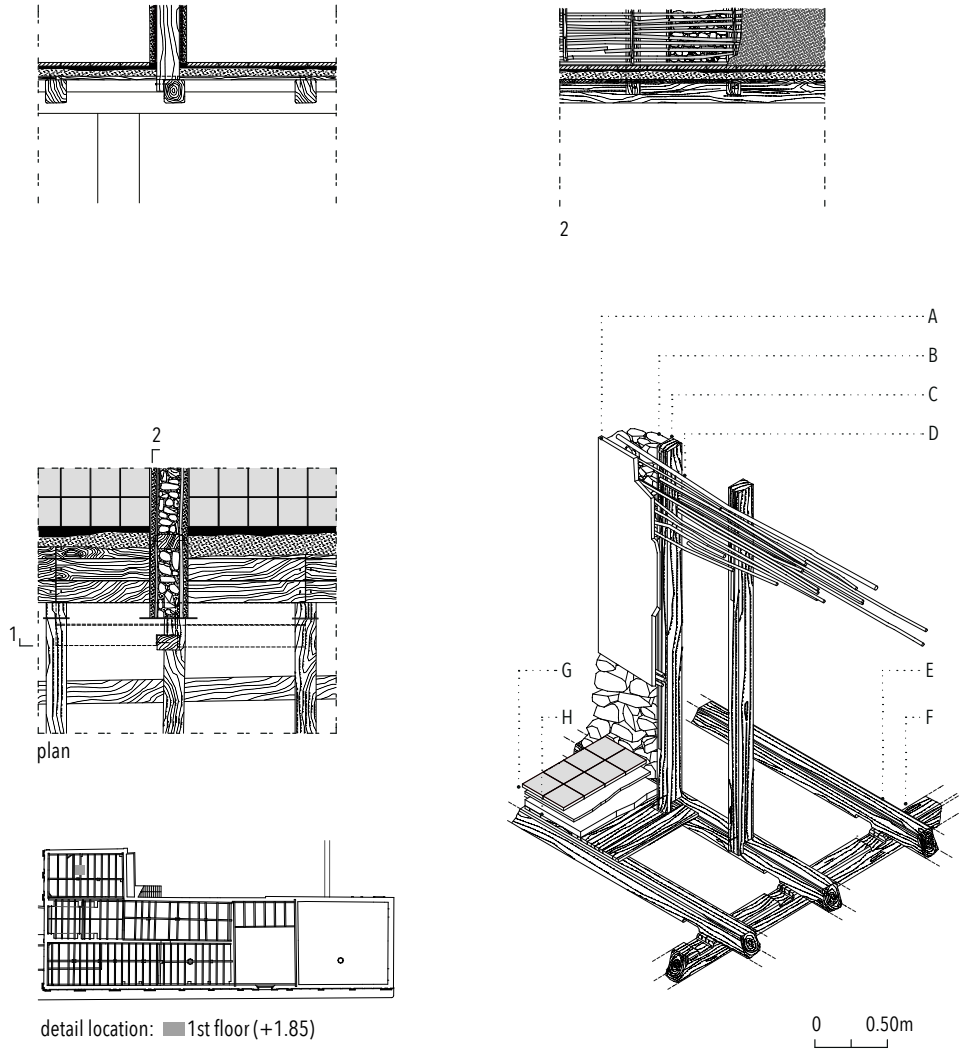
observations Tobriner draws from other surveyed *case baraccate* in comparison with *Pombalino* buildings: "But whereas the lateral resistance of the *gaiola* is in the internal walls, the lateral resistance in the *casa baraccata* is in the external walls (...)".[121] In this case, all the interior walls of the first floor, both orthogonal and parallel to the main facades, are timber-framed walls, whose raw components and proportions (ratio of height to floor area) are different to the interior *Pombalino* walls.

Despite the simplification of the external wall compared to Vivenzio's anti-seismic house model, the main construction principles were respected: the continuity of the main vertical uprights from ground to the roof,[122] the interlocking of the components, the execution of the ground floor higher than street level, and the protection of the timber framework by a thick plaster (*Figures 4.38*, *4.39*, *4.40*).[123]

Of interest is the connection between the interior wall, orthogonal to the main facade (type iii), and the floor structure (*Figure 4.38*, top). Its function is similar to the connection found in *Villa Isabella* (1912-1914), a restored timber-framed palace in Gallico (Calabria)[124](*Figure 4.38*, bottom, right). In the Bishop's Palace, the connection is provided by the half-lapped joint of each vertical post, while in *Villa Isabella* the wooden joist is connected to the vertical post by its mortise-and-tenon joint.

Two other differences between *Pombalino* and *Borbone* systems should also be noted. Firstly, the timber components of the Bishop's Palace are very irregular in the cross-section, and are affected by substantial dimensional shrinkage, swelling, and cracks, especially next to the nail. For its part, *Pombalino* reconstruction relies on a prefabricated process including standardised dimensions of all components: consistency in the selection, regularity, and cutting of the wooden components, especially for the vertical posts. Secondly, the floor structure in the Bishop's Palace, as well as in the coeval Calabrian buildings, is composed of tiles placed above the mortar screed that is in turn placed above the wooden planks (*scandali*), nailed to the wooden joists along the direction orthogonal to them. *Pombalino* floor structure is similar, with wooden planks generally 22 mm thick and 16 cm wide, but omitting the tiles and therefore weighing less and reinforcing by wooden members placed orthogonally to the wooden joists (*tarugos*).[125]

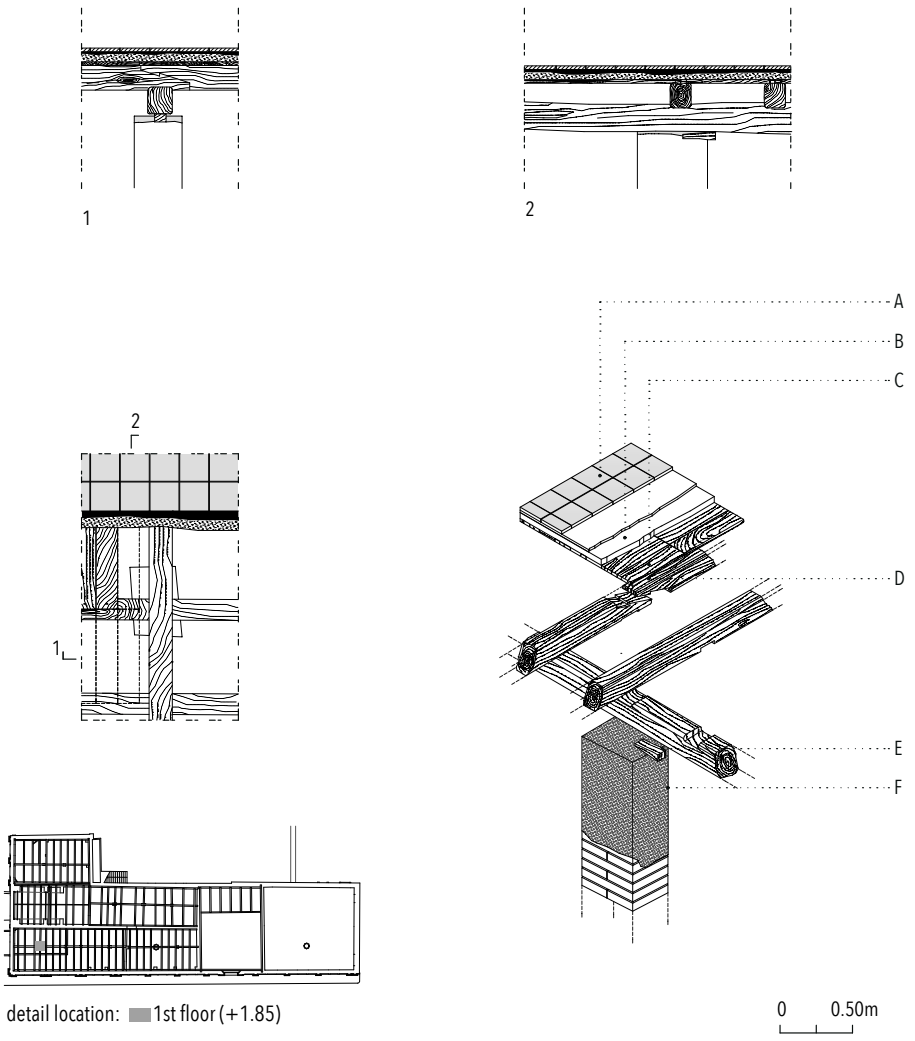
[121] (Alessa, J. 1999)
[122] see *Appendix C.2.2*, *Photograph no. 2*
[123] *Figures 4.35* and *4.37* reproduce what is shown in *Appendix C.2.2*, *Photographs nos. 1* and *4/5* respectively.
[124] (Bianco, A. (ed.) 2010, 91-108)
[125] (Mascarenhas, J. 2004, 112)



wall: A. lime plaster (3cm); B. stone infill (15cm); C.vertical posts (15X10cm); D. canes nailed to the vertical posts;
floor: E. floor joists (16X14cm); F. floor joists connected by cross lap joints (13X17cm); G. tiles (20X20X2.5cm)+screed (7cm); H.wooden planks (14X82X2.5cm)

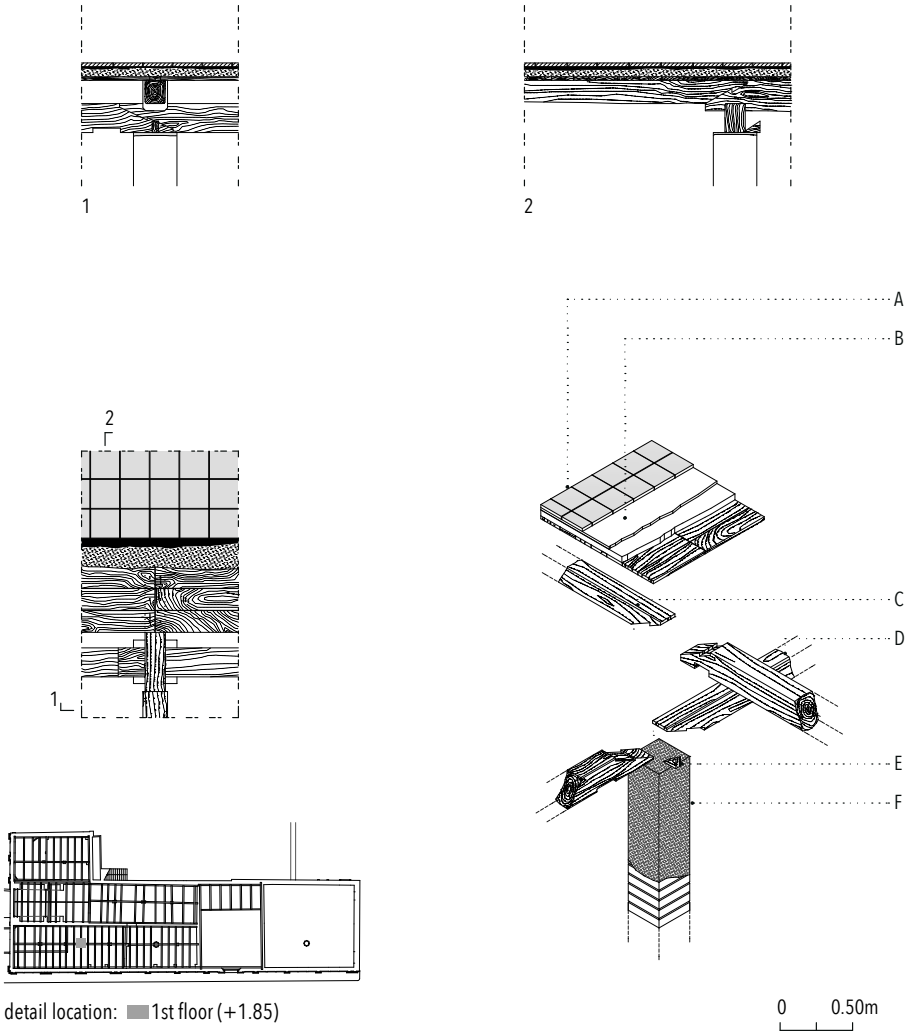


Figure 4.38 – Detail A: Connections of vertical posts in the Bishop's Palace (late 18th century) (drawing, top) and photo (bottom, left) (© S. Stellacci) and in *Villa Isabella* (early 20th century) in Gallico (bottom, right) (Bianco, A. (ed.) 2010, 108)



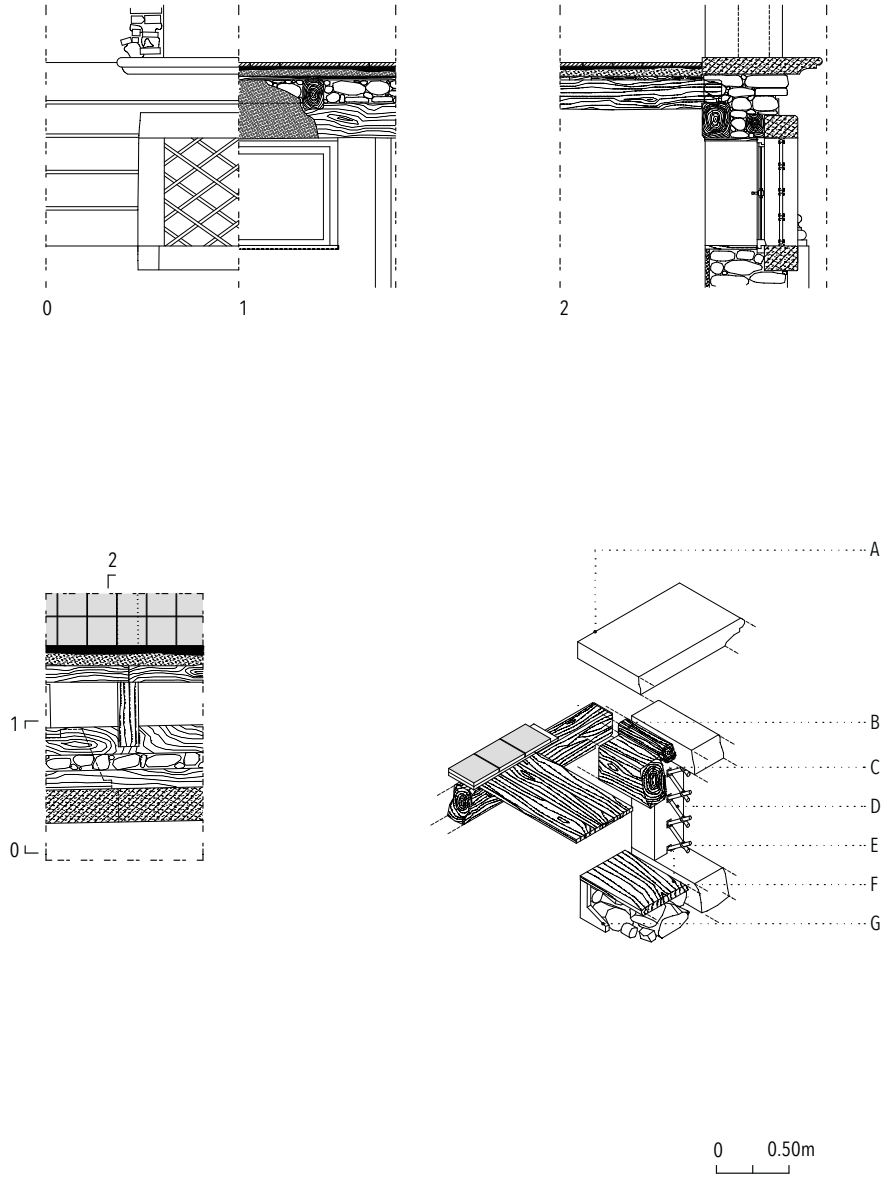
floor: A. tiles (20X20X2.5cm)+screed (7cm); B.wooden planks (15X80X3cm); C. floor joists (14X17cm) connected by *Trait de Jupiter* joints ; D. floor joists (13X17cm); E.wooden wedge; F. brick pillar (49X33cm)

Figure 4.39 – Detail B: Brick pillar and wooden joists (© S. Stellacci)



floor: A. tiles (20X20X2.5cm)+screed (7cm); B.wooden planks (15X80X2.5cm); C. floor joists (14X16cm); D. floor joist (14X20cm); E.wooden wedge; F. brick pillar (30X30cm)

Figure 4.40 – Detail C: Brick pillar and wooden joists (© S. Stellacci)



A. granite cornice; B. wooden architrave; C. wooden beam above the external wall; D. iron grating diagonal mesh shaped ("*occhio abbottato*"); E. windowsill made of wooden planks; F.rubble stone masonry wall; G. plaster

Figure 4.41 – Detail D: Connection of external wall to wooden joists (© S. Stellacci)

4.4.2.2 Roof structure

The roof of this palace – today in a precarious state of conservation and partially collapsed – most probably dates back to the end of the 18th century. Its structure is composed of an alternating sequence of timber king post trusses[126] and tie beams, covering a nominal span of approximately 11 m. There is a uniform span between them ranging from 1.00 m to 1.15 m. The secondary structural components are wooden purlins and principal rafters, covered by tiles. The density of the structural elements of the roof allows the anchoring (nailed) of the wooden planks that form a false ceiling ending in a simple cornice (*Figure 4.42*).

Being composed of a set of various elements firmly connected to each other (without any other bearing support in the building, e.g. pillars or intermediate walls), the wooden truss is generally viewed as an optimal solution for seismic prone areas.[127] Indeed, the king post trusses do not transmit any thrust to the peripheral walls. The rafters, subjected to combined compressive and bending stress, transmit the same horizontal and opposite force to the thrusts which are absorbed by the tie beam; the king post tends instead to be pushed upwards by the struts and then supports the tie beam by means of a metallic stirrup; the principal rafters in turn reinforce the struts and are compressed. Each king truss, connected to its respective tie beam, is able to remain in the same plane thanks to the metallic stirrup; the king truss is able to deform as the load changes.

The covered span of this roof, slightly more than 41 palms, is very similar to the Vivenzio/Ferrarese model in the lateral volumes of the tripartite block whose roof structure is composed of queen posts (*capriata palladiana semplice*),[128] however the trusses executed in the Bishop's palace include a king post, as previously noted. In the absence of other surveyed case studies for comparison, we can also refer to the nearby Borgia Palace (1920s?) whose roof layout is very similar (an alternating sequence of king post trusses and tie beams) as can be seen above in the postcard of the *Borgia Palace* in Mileto (*Figure 4.06*). It can be assumed that this solution was employed when the span to be covered was limited.

An important aspect is taken from Ferrarese's technical drawing of the anti-seismic model of *case baraccate*: the use of bracing frames longitudinally to the truss plane (corresponding to the north-south direction in this case study). Although the X-bracings of the Bishop's Palace are very irregular in their cross sections, these members act to brace the double king trusses – in the absence of these transverse components, the trusses may be subject to stacking in case of horizontal forces, within a phenomenon commonly defined as *domino effect*. Similar diagonal components were also surveyed by Tobriner in the now-demolished building in Filadelfia.[129]

In addition to the X-braces orthogonal to the plane of the king trusses, additional strength is provided for this roof structure by connecting the vertical posts to the bottom timber beam by carvings alternating on their inner and outer faces, in few points of the surveyed external wall (*Figure 4.42*). Connections between vertical and horizontal structures increase the stiffness of the whole framework. Similar alternated carving of posts on their inner and outer faces can prevent the overturning of the facade (*Appendix C.2.2*, *Photographs nos. 22-24*). A

[126] In other seismic prone zones, as in Abruzzo region, collapse mechanisms were prevented by the called *capriate impallettate* (trusses fixed by stakes), i.e. the tie beams were placed over the facade plane and fixed by a wooden stake. These devices, dating from the second half of the 15th century, can be encountered in numerous historic buildings in L'Aquila. Some informations and references are provided by Carocci (Nobile, M.R.; Scibilia, F. (ed.) 2016, 155-168).

[127] Among many scholars, an overview of traditional king trusses slight inclined within the Mediterranean basin with reference to various treatises is extensively discussed by Munafò (Munafò, P. 2002).

[128] *Chapter 3*, *section 3.3.2*, *Figure 3.11*

[129] (Tobriner, S. 1983, 137)

comparison far across time between the wooden roof structures of the Bishop's Palace and an ancient vernacular hut in northern Latium (Allumiere) – reconstructed in 1990 –[130] can be deduced in *Figures 4.42-4.43*. This is a simple gable roof with struts; the span to be covered is about one half of the Calabrian palace (5.10 m); three rows of wooden posts connected to double ridge beams are stuck in the ground, but the common point in these cases is in the connection of the vertical posts to the top beam, to form a three-dimensionally sound structure (*Figure 4.44*).

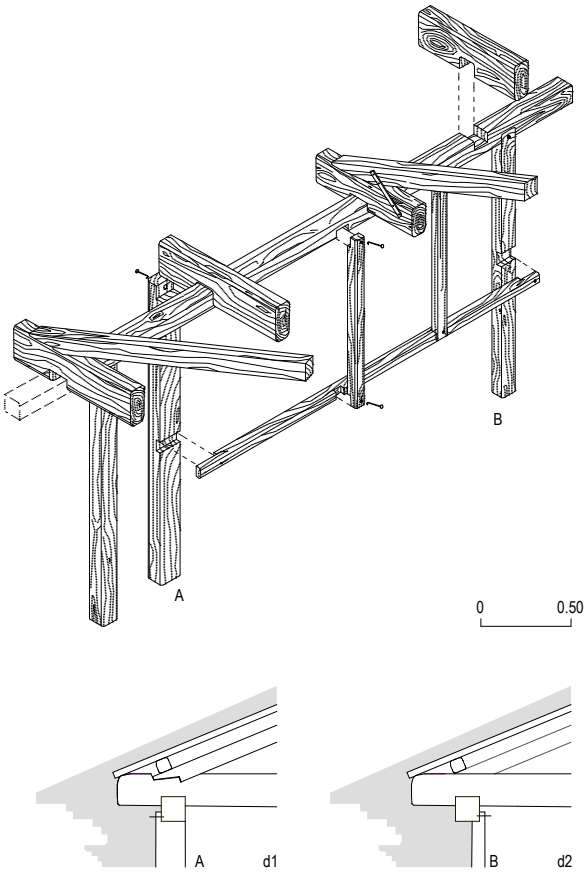
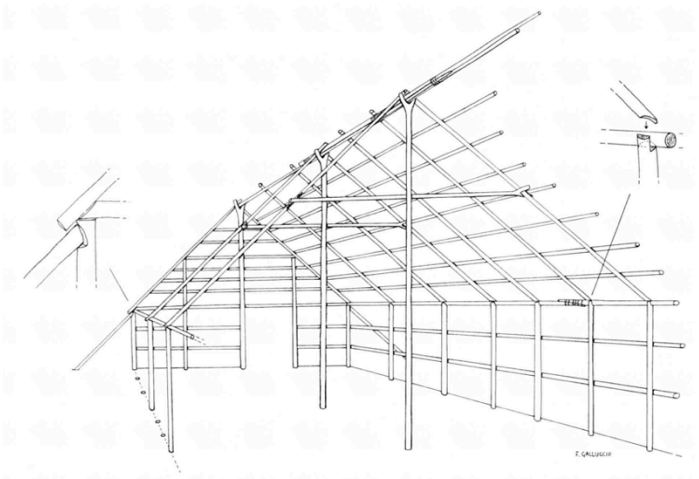


Figure 4.42 – Detail of roof: (d1) vertical post and king post truss carved on its outer side; (d2) tie beam and vertical post carved on inner side (© S. Stellacci)



[130] Following traditional local techniques, two huts, one circular and the other rectangular, were reconstructed by the *capannari* (hut builders) in 1990 in Giovita (close to Rome) (Brocato, P.; Galluccio, F. 2001, 283).

Figure 4.43 – Hypothetical layout of the hut at Giovita (Northern Latium) (Brocato, P.; Galluccio, F. 2001, 293)

Another device introduced to increase the transversal stiffening of the roof structure is a set of beams placed orthogonally to the plane of the king trusses, each connected to one king truss by a metallic bracket (*Figure 4.44*).

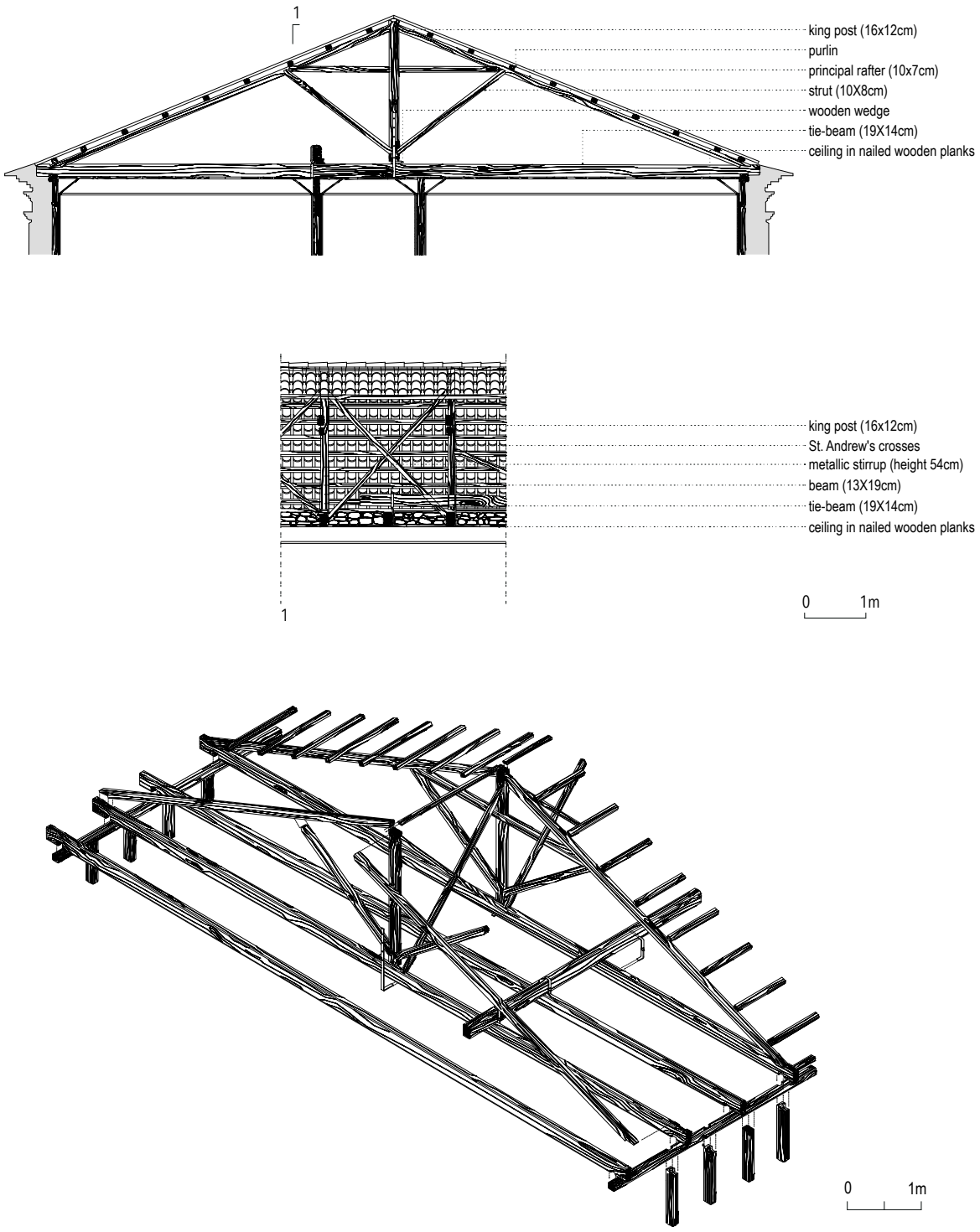


Figure 4.44 – Cross sections and isometric view of the roof structure of the Bishop's Palace of Mileto (© S. Stellacci)

4.5 Discussion and final comments

The post-seismic activities in Lisbon and in Mileto embodied top-down processes, complete rebuilding, and the use of similar structural systems incorporated into a gridded urban plan. Although they had these aspects in common, their urban settings were fairly dissimilar. The centre of Lisbon, capital of a vast colonial empire and the most populous city of Portugal with 190,000 inhabitants, was rebuilt within a perimeter of 560 x 380 m in the same place to replace "the cluster of square facades and small triangular roofs".[131] Mileto, a small town of less than 2,000 inhabitants, was repositioned from its old settlement in 360 x 550 m. Lisbon's dynamic mercantilist culture made it a melting pot with increasing social cohesion,[132] whereas Mileto persisted in its social and economic stagnation even after the seismic shocks and the optimistic initiatives of the Neapolitan engineers.

For Mileto, the convergence of two small streams and proximity to the medieval town – a sort of umbilical cord – influenced the new location of the city. Whereas the organic medieval tissue (the *Castrum Melitense*) had been a village perched on three hilltops along a typical narrow and elongated spindle-shaped pattern, Mileto's reconstruction followed a new grid-based pattern in a new lowland location. This entirely new town maintained its territorial relations via the old Royal Road.

Reconstruction in Lisbon took place at its original site, which is also a lowland area. Pombal's purpose similarly aimed to replace the chaotic former streetscape with a new regular urban tissue; however, physical and technical continuities were crucial in the new plan. Rossa emphasizes that Lisbon's recovery from 1755 embodies a sort of creativity: "Creativity was more in the wisdom exercised in the interpretation of the place, rather than in the invention and composition of new architectural forms".[133]

The memory of the past is somehow incorporated in both cities: in Lisbon through the maintenance of some invariants (location of former public spaces, visual and connective relationships) and pre-existing buildings (convents, churches) completely integrated in the new urban layout; in Mileto through the re-use of building materials and architectonic pieces (jambs, lesenes).

Shifting the focus from the urban to the architectural scale, a preliminary comparison can be drawn based on two selected case studies. Despite increasing scholarly interest in traditional anti-seismic structures of the Mediterranean Basin, little comprehensive research has been based on comparison of case studies. We have attempted to retrace two narratives of timber-framed buildings through a complementary reading beyond their surface finishes.

The first case study is a multi-storey building included in an elongated uniform block, similar to other surrounding buildings. It was the result of individual initiatives under direct centralised management on a collective scale – probably the most saliently modern aspect of these post-earthquake works. Each apartment fulfils the rentable residential function, "the modern local urban type (a mixed-use, low-rise, multi-tenancy, structurally sound and fire-protected building)",[134] whose relationship with the public space is limited to the main lot frontage on the main road.

For its part, the Calabrian palace exemplifies the firm basis of the planners' intentions yet also the

131 "(…) o amontoado dos quadradinhos das fachadas e dos pequenos triângulos dos telhados (...)". (França, J. A. 1987, 22)
132 The economic dynamism engendered by the *parvenu* bourgeoisie in Lisbon was not accompanied by cultural dynamism, as underlined by França (França, J. A. 1987).
133 "A criatividade estava mais na sageza exercida na interpretação do lugar, do que na invenção e composição de novas formas arquitectónicas." (Rossa, W. 2015, 29)
134 (Brand, D.; Nicholson, H. 2013, 180)

shortcomings of the frequently-unfinished *Borbone* reconstruction works. Being an episcopal residence, it was not included in the rectangular blocks, though it shares other similarities with coeval buildings such as the prominence of the entrance door in the main facade and the use of materials from the Norman epoch.

Following the different values expressed by Riegl (1858-1905) for built heritage,[135] the Portuguese case study differs from the Calabrian one because its value can be understood as *unintentional*, because this building was only intended to make a profit; conversely, the Bishop's Palace intended to express the symbolic importance of the clergy, making it an *intentional monument*. Following Riegl's thought, the historic value of both buildings, in terms of their degree of authenticity, was unquestionable when the on-site surveys were carried out by the author of this thesis, despite being compromised due to an ongoing rehabilitation process (in the first case) and the neglect (in the second).

Pombalino and *Borbone* anti-seismic building stocks arose from Classical code interpreted in a pragmatic approach dictated by emergency conditions. Their technical sophistication (*fabrili subtilitate*) was achieved through modularity and accuracy (*officinatoris exactio*) in the construction details. This rigour can be perceived throughout the analysed case studies,[136] such as in the sort of *enfilade* of the openings from the facade to the interior to the windows of the tiny patio, or in the refined timber pillars framing the loggia of the Bishop's Palace and in its roof structure.[137]

Similarly strict principles resulted in different architectural grammars, as seen in the two analysed buildings, firstly due to the different proportions of the parts (i.e. the predominant sense of verticality and being a part of a continuous building block *vs* the horizontal development of the facade and the block as an isolated construction) as well as due to their distinctive architectural details. *Plastic* and rhythmic motifs of the Calabrian edifices contrast with the simpler, more severe *Pombalino* language that arose from the national military *plain architecture* (the so-called *arquitetura chã*),[138] and French influence in striking constrast with the contemporary Baroque Palace of Queluz in Sintra. Standardised and pre-defined architectural models were followed in the *Baixa* district. The differences in their decorative structures can be observed for example in the simple *Pombalino* lesenes and the absence of hierarchy in the openings of the ground floor, *vs* giant fluted lesenes and prominence of the main access in the Calabrian building.

As regards their construction systems, the key load-bearing structure of both buildings is the timber frame filled with stone masonry blocks. Under static and dynamic actions, the wooden structure is crucial, while the infill cooperates by providing additional stiffening. The function of the timber elements is substantially different in the two cases. In the Portuguese buildings, the bearing system works under static and dynamic loads. Conversely, in the *case baraccate*, the wooden frame does not take part (or plays only a limited role) in static field; under dynamic action, the wooden skeleton provides additional tensile strength to the masonry. Timber frame

[135] (Riegl, A. 1985)

[136] The technical and formal caution encountered in the Bishop's Palace owed to the financial possibilities of the resident and the function of the building. However, several other palaces in Mileto and in the other post-earthquake rebuilt towns provide remarkable construction details, which are often hidden or in severe state of decade.

[137] See the alignment of the openings of *Pombalino* case study in *Appendix C.1.4*, *Photograph no. 26*, the timber loggia and king trusses in *Appendix D.2.2*, *Photographs nos. 7* and *11-14* respectively.

[138] The Portuguese term *chã* (meaning *flat*) was translated by Kubler in *plain architecture*, following Júlio de Castilho's definition. It is intended as "vernacular architecture, related to living dialect traditions more than to the great authors of the remote past." (Kubler, G. 1972, 3)

walls characterise the Portuguese system: a framework of timber filled with masonry (*gaiola*), while the Italian system is characterised by masonry, reinforced with timber frames (*sistema baraccato*).

One final remark concerns the current state of these buildings, which epitomizes the most common condition of these two types of constructions. The analysed building in *Rua dos Fanqueiros* is a hotel, partially reformulated in its interior layout and greatly reinforced by metallic structures, yet faithfully restored in the external volume.[139] Conversely, the Bishop's Palace is in a complete state of abandonment since its owner is not interested in recuperating it and the municipality lacks the economic resources to purchase and recover it.[140]

Despite the differences of these case studies, each one's building processes arose from a common Enlightenment pragmatism and purpose for counteracting seismic force. Disproving the scepticism of the early historiography on these historic timber-framed buildings in both contexts – in Lisbon for monotony and in the Calabrian towns for incompleteness[141] – the value of this heterogeneous group owes to the timeliness, coherence, and distinctiveness of their construction system. The significance of this type of historic buildings should also be understood by considering that the town and construction planning resulted from deliberate legislative acts in spite of limited economic resources. Expressions of well-founded urban principles and technical solutions remain as evidence of the human ability to cope with natural disaster through a process in which the individual (owner's) interest was rethought and channelled into a collective program.

[139] The greatest alteration to the external volume on the main street is observed in the attic, whose perimeter is now delimited by a continuous railing, embellished by three dormers that have replaced the tiny central dormer shown in *Figures 4.17* and *4.27*.

[140] A continuous effort to raise general awareness about the importance to preserve the Bishop's Palace of Mileto and to improve the knowledge on Calabrian anti-seismic urban design and construction system has been made by Dr. N. Ruggieri and the team coordinated by professors M. Zampilli, F. Geremia, G. Salerno, and the author of this thesis. Preliminary results – gathered during the on-site survey on March 2015 of this case study and the research at the University of Roma 3 – converged in the Conference held in Lisbon, *Historical Earthquake-Resistant Timber Framing in the Mediterranean Area* (*HEaRT* 2015) (Cruz, H; Machado, A.C.; Candeias, P.X.; Ruggieri, N.; Catarino, J.M. 2016, 125-134, 135-145, 205-226), whose first edition took place in Cosenza in 2013 (Ruggieri, N.; Zinno, R. 2015). From the survey of this Palace in March 2015 onwards, the team sought a preliminary protocol between the University of Roma 3 and Mileto municipality for a project to rehabilitate this Palace.

[141] Among many, Ratton judged Manuel Caetano and Eugénio dos Santos negatively (França, J. A. 1987, 204).



CHAPTER 5 – Towards an informed problem-solving approach: Multi-criteria analysis of rehabilitation techniques for timber frame wall

5.1 Introduction

"But the difference between the present and the past is that the conscious present is an awareness of the past in a way and to an extent which past's awareness of itself cannot show." (Eliot, T.S. 1921, 46)

Living urban heritage[1] consists of vestiges of the past that embody cultural memory and provide guidance for their own future use. The identity of the community is expressed by tangible evidence in those historic buildings that remain notable for their typological, architectural, and structural systems.

The significance of the built heritage should therefore be handed down while safeguarding those material features expressed by specific construction process and architectural solutions. Additionally, its value relies on the symbolic and functional meanings attached by its local communities over the centuries.

The interventions on historic buildings range between two opposite poles – full conservation of the construction for the safeguarding of its physical authenticity *vs* more intrusive approaches which, taken to the extreme, encompass full demolition to meet current code-requirements and users' demands or preferences.

The selection of proper intervention solutions is often a demanding task and requires balancing a variety of criteria from multiple stakeholders involved in the current practice. Emblematic controversial questions are addressed below through case studies of *Pombalino* buildings in downtown Lisbon and their internal vertical structure.

Before diving into different operational strategies, a preamble on key factors that the technicians – designers, architects, engineers, contractors – have to consider nowdays will clarify the reasons underpinning the methodology proposed in the final section of this thesis, whose ultimate goal is the assessment of the best intervention works (*section 5.4*).

Firstly, as discussed in the previous chapters, *Pombalino* buildings are a group of multi-storey standardised blocks integrated in a well-ranked and regular urban layout.

Dealing with adjacent buildings that were originally harmonised in a consistent urban plan and later turned into a heterogeneous group in dating, morphology, and structural system is now a common task all over. In such cases, an integrated planning policy is required.

[1] Historically stratified built environments are one type of diffuse cultural heritage (*patrimonio culturale diffuso*), whose value has been recognised in Italy since 1939 (Laws no.1089, no.1497). The Italian legislative framework on this issue also includes the concept of minor architecture that comprises ordinary traditional or vernacular buildings and adjacent land within their curtilage, those under indirect safeguarding constraint. The valorisation of the diffuse cultural heritage in Italy currently is intended to invest in the tertiary sectors of the economy on the basis of regions' traditional identity. A brief overview of the earliest urban safeguarding strategies in Portugal is provided by (Cabrita, A.R.; Aguiar, J.; Appleton, J. 1992, 28-31).

The need to safeguard ordinary historic buildings has been extensively debated since the Charter of Krakow[2] and long before. In Portugal, the question was addressed in 1985[3] but nowadays, in many cases, with low impact upon the *communis opinio* and the conventional praxis. In fact, highly intrusive works built according to contemporary requirements have been more easily accepted in ordinary buildings rather than in a monumental artefact: the preservation of the *tangible memory* is a value endorsed by the community when it regards churches, monuments, palaces, or buildings of special interest. Conversely, the preservation of the *tangible memory* for serial architecture, a category in which the *Pombalino* buildings fall, is less certain and must be defended.

A second observation can clarify the significance of the proposed methodology. Bearing in mind the research focus is around "the single building as a moment of a continuous process, testified by its ability to express the collective values of the civilization to which it belongs", [4] each *Pombalino* building comprises a record of the social and cultural changes of the local community in terms of use and habits: these constructions have been largely influenced by a seesaw of economical interests and taste in a timespan of more of two hundred years. In fact, *Pombalino* buildings arose as a notable expression of the emerging merchant class, later devoted to housings for low-income tenants, banks, and service accommodations. Their importance continued to decrease until the real estate boom of the past decade, which has viewed them as mere consumer products (financial investments), malleable according to the requirements of whomever the current owners may be.

At a closer look, the shift of the importance attributed to this area by the community compared to other districts in the city can be seen by analysing the uneven density of the population rate in downtown Lisbon over the years. A long period of deadlock and neglect followed a phase of heavy alterations and demolitions of *Pombalino* buildings from the 1960s until now. Consequently, the preservation of this building stock and the dynamism of the whole parish[5] have not been consistently upheld; furthermore, several alterations remain now as an unsightly legacy. In addition to notable architectural features introduced in these buildings since the second half of the 19th century (e.g. signboards, store carports, ceramic tiling of the facade), numerous structural alterations have taken place since the introduction of new construction systems and materials[6] (*Figure 5.01*). Besides the material decay and some congenital weaknesses worsened by the prolonged neglect of these buildings,[7] many have undergone structural alterations. These include enlarging the openings at the groundfloor, adding extra floors, demolishing internal structures, and introducing new systems (lifts, staircases, overhanging structures to the rear). These alterations cannot be considered historical overlapped layers to be safeguarded. Beside the loss of architectural integrity and authenticity, uncritical confidence placed in reinforced concrete – even if countenanced in the art. 5, Charter of

[2] In agreement with the programmatic statements included in the Venice Charter, the Charter of Krakow (2000) extends the attention of the scientific community from the monument to the built environments and to historical buildings in rural and urban areas (ICOMOS 1964)(The Charter of Krakow 2000).
[3] (Decree Law 13/1985)
[4] "L'edificio singolo come momento di un processo continuo, testimoniato dalle sue capacità di esprimere i valori collettivi della civiltà a cui appartiene." (Strappa, G. 1995, 37)
[5] This process of desertion was reflected in all the historical districts of the city, and it was followed by a considerable neglect of these constructions.
[6] This district counts a large number of examples of the imposition of new architectural styles and ways of living; one of the most remarkable is the Grandella Warehouses (1891).
[7] In addition to the housing rent freezing and the difficulty of adapting the urban and private accessibility to new users' requirements, the establishment of new shopping malls in other areas of the city produced depopulation and thus the decline of this parish especially during the 1980s (Mascarenhas Mateus, J. (ed.) 2005, 107).

Athens (1933) – results in mechanical incompatibility between the new system and the original (e.g. increasing mass, alterating the load path, and decreasing of lateral load resistance).

Countering the trend of neglect in previous decades, significant real estate investment has been fostered in the last five years (2012-2017) by the centrality of this building stock and new market demand linked mostly to the increase in tourist flow. This increasing demand has been fostered by a permissive municipal policy, through specific funding programmes and a progressive simplification of legislative requirements (s*ection 5.2.4*).

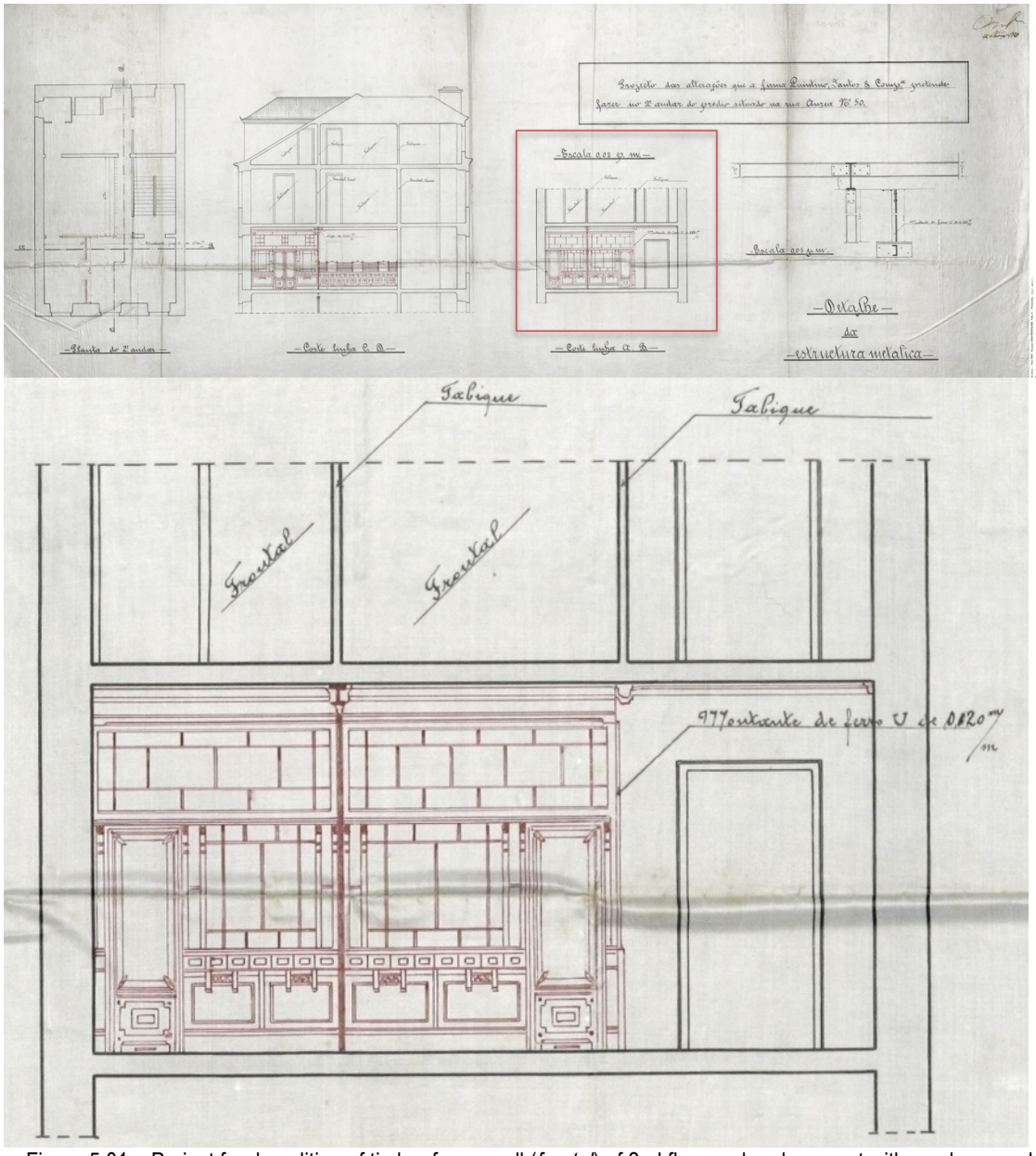


Figure 5.01 – Project for demolition of timber frame wall (*frontal*) of 2nd floor and replacement with a column and metallic beam (in red) in a *Pombalino* building at *Rua Aurea* no. 50 (AML, PO 17361, 4853, 1ªREP-PG-1920, folha 4)

Negative judgment of current interventions on these buildings is grounded on the analysis of the works carried out in the last five years, many of those stemming from the principle that the building can be reduced to an

emptied box, exactly as occurred in the early of the 20th century when the authenticity of some *Pombalino* buildings was erased by arson.

Campanella and Mascarenhas Mateus characterize this *fachadism*:

> "The buildings are emptied of their contents, their souls ripped apart, delegating to the old masonry that are left standing (usually the perimeter), the only use still permissible, the simple disposable 'box'. The function corrupts the building, mortifies it, transforms it to the point of making it unrecognizable".[8]

Apart from these key conditions – ordinary building type, intrusive interventions over time – private ownership is another aspect that should be considered. In the absence of specific guidelines or technical rules, individual/private choices regarding intervention on historic buildings are frequently short-sighted.[9] Thus arises the main question of how a priceless and irreplaceable resource should be managed within an integrated planning policy by imposing constraints on the private rights of the building owners.

This work shall show how interactive and collective deliberation is needed to support the decision-makers (building owners or users). The proposed procedure is an attempt to objectify the assessment of a wide range of possible interventions through the involvement of a multidisciplinary group of experts whose scholarly interest is the preservation of historic buildings. These researchers are Dr. Elisa Poletti and Prof. Graça Vasconçelos from the University of Minho and Dr. Giovanni Borsoi from TU Delft, together with Prof. Vasco Rato and the author of this thesis from ISCTE-IUL.

[8] "Os edifícios esvaziam-se dos seus conteúdos, arranca-se-lhes a alma, delegando às velhas alvenarias que são deixados em pé (normalmente as perimétricas), o único uso ainda admissível, o de simples 'caixa' descartável. A função corrompe o edifício, mortifica-o, transforma-o ao ponto de o tornar irreconhecível". (Campanella, C.; Mascarenhas Mateus, J. 2003, 8)

[9] The primacy of a grounded legal framework for safeguarding heritage is disputed by the thought of André Chastel (1912-1990), recalled in the preface to Bianco's book: "the ancient buildings are not preserved by a decree: the owners of each house preserve or ruin their houses; the inhabitants of each country replace or maintain the old stones." (Bianco, A. (ed.) 2010, 11).

5.2 Rehabilitation of *Pombalino* buildings in downtown Lisbon

Various factors could influence the features and the performance of the *Pombalino* buildings, as well as the types of intervention possible in them. These are analysed below individually and within their synergies in order to approach the multifaceted (conceptual and technical) process of rehabilitation.

5.2.1 Multi-stakeholders and key factors in the rehabilitation of Pombalino buildings[10]

In addressing the rehabilitation of *Pombalino* buildings, the sphere of interest gravitates around three key factors:

- the historical building itself;
- its owners and/or users: decision-makers;
- technicians: experts in traditional building structures (e.g. architects, timber engineers, chemists).

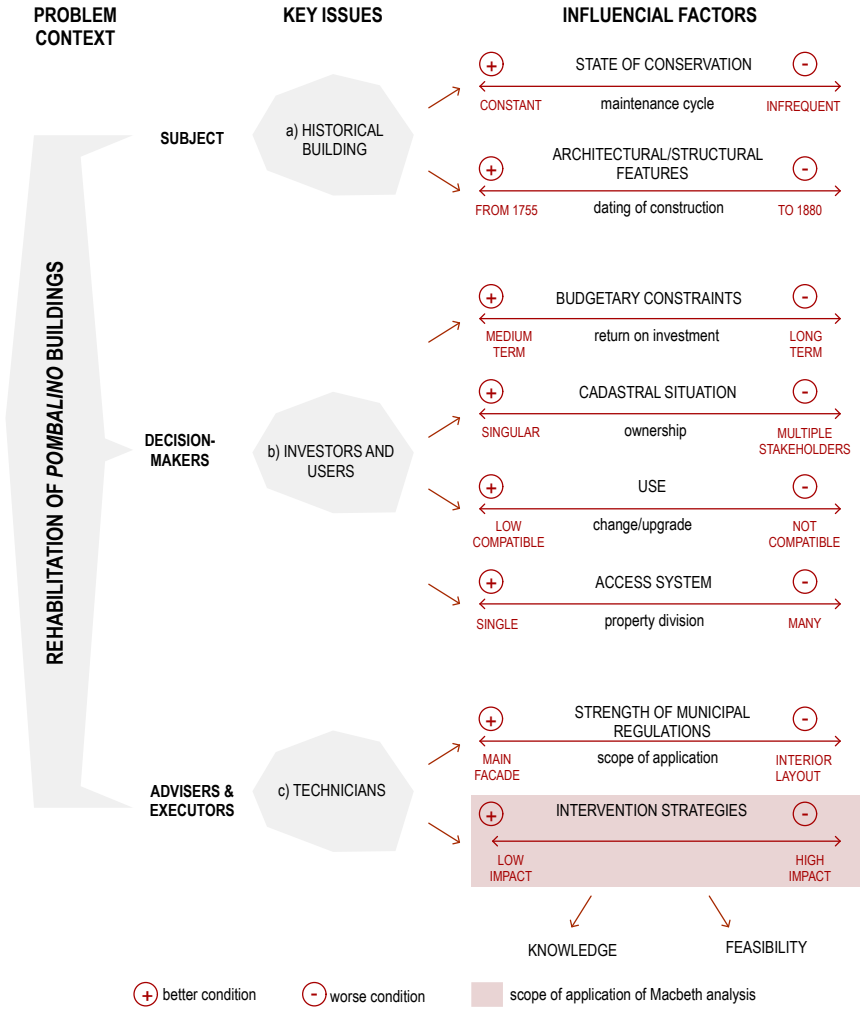


Figure 5.02 – Flow diagram of key factors in rehabilitation of *Pombalino* buildings (© S. Stellacci)

[10] This analysis regards constructions within the perimeter of *Baixa Pombalina* – as defined in 2011 (CML 2011b, art.2) – originally intended for renting, whereas palaces, churches, and other buildings of special interest are not included due to their specific features.

Figure 5.02 shows these intertwined agents and aspects. These are influenced by the key aspects identified on the horizontal arrows, which range from more favorable (+) on the left to worse (-) conditions on the right.

(i) *historical building*: The intervention strategy strongly depends on the original layout and state of conservation of the building. These factors influence the structural reliability of the building itself and its components under cyclic and dynamic loads (*Figure 5.02a*).

The structural layout of *Pombalino* buildings greatly varies according to the dating of building execution. The quality of their construction systems generally decreased with the passing of time.

In fact, during the earliest years of post-earthquake activities, this system was characterized by regularity, accuracy in details, and higher qualities of materials. The buildings consist of a three-dimensional structure with braced frame timbers with Saint Andrew's crosses, parallel and orthogonal to the main facade (e.g. in *Rua Augusta* nos. 131-135).[11] Later, these internal load-bearing walls were only executed parallel to the facade (e.g. in *Rua dos Sapateiros* nos. 82-86).[12] In many cases, the accuracy in details was also gradually lost.

Moreover, in good quality constructions, the depth of the entire lot is covered by joists parallel to the main facade; each joist is generally a single piece (and not two nailed members), and acts as a tie rod. Iron pieces are used in stone masonry walls nailed to the wooden beams to increase the binding effect. Later or when the owners had modest incomes, shorter pieces were employed resting on the internal walls, thereby partly decreasing the structural effectiveness.[13]

Over a period of one hundred years, the *Pombalino* system degenerated into the so-called *Gaioleiro* system with a substantial loss of overall stability in different aspects (e.g. decrease in stiffness and flexural resistance of the floors, lower material mechanical properties,[14] local structural weakness due to the loss of the structural redundancy) owing to the lack of systematic execution of the internal timber framework, as previously mentioned (e.g. in *Rua Augusta* nos. 76-84).[15]

In addition to problems stemming from poor design[16] in buildings of the last decades of reconstruction, many have suffered damage from neglect. Regardless of a continuous growth of resident population in Lisbon, a considerable decrease of occupancy was continuously registered from 1911 to 2011 in the district of Santa Madalena and São Nicolau **–** the old extinguished districts[17] – with a loss of 10,654 inhabitants, a loss of 87% of those who initially lived in these houses (*Table 5.01*).

[11] The layout of this case study refers to Mascarenhas's survey carried out in 1984 (Mascarenhas, J. 2004, 159)
[12] see footnote 11 (Ibid., 160)
[13] (Appleton, J. 2008, 410)
[14] From the second half of 19th century soft wood, whose sapwood (the outer section) is especially prone to infestation, was most widely used as shown in recent on-site surveys (Ibid., 31).
[15] see footnote 11 (Mascarenhas, J. 2004, 161)
[16] Poor design means in literature "insufficient dimensions, inefficient joints, inefficient overall arrangement" (Serafini, A.; Riggio, M.P.; González-Longo, C. 2017). See footnote 140.
[17] As result of an administrative reorganization, the map of the ancient parishes of the Lisbon was reconfigured in 2012. Twelve ancient parishes of the historic centre of Lisbon (e.g. *Castelo*, *Madalena*, *Mártires*, *Sacramento*, *Santa Justa*, *Santiago*, *Santo Estevão*, *São Cristóvão*, *São Lourenço*, *São Miguel*, *São Nicolau, Sé* and *Socorro*) were regrouped into a single parish, *Santa Maria Maior*, whose buildings correspond to the 5% of the all constructions of the city.

Table 5.01 – Resident population in Lisbon Council and in the *Madalena* and *São Nicolau* districts from 1864 to 2011

	1864	1878	1890	1900	1911	1920	1930	1940	1950	1960	1970	1981	1991	2001	2011
Lisbon Council	190,311	240,740	300,984	351,210	431,738	484,664	591,939	694,389	783,226	802,230	760,150	807,937	663,394	564,657	547,733
Madalena + *S.Nicolau* districts	11,914	11,238	11,356	10,982	12,549	7,864	9,859	8,561	5,677	5,529	3,610	3,159	1,974	1,555	1,895

To counteract the decay of physical components, constant maintenance actions reduce the costs of interventions necessary in the future, either by preventing unpredicted failure, addressing pathologies, or repairing in-service defects.[18]

What should be emphasized is that the seismic behaviour of *Pombalino* buildings is influenced by their original structural weakness and material decay, as well as by alterations resulting from human activities to accommodate different use. These changes in the external facade and in the whole construction (e.g. enlargements of the door windows at ground floor, adding new structures in the rear or extra floors, lifts) have generally caused an over-strength dissymmetry in plan and elevation and have compromised the original configurations in terms of load resistance (*Figure 5.03*).

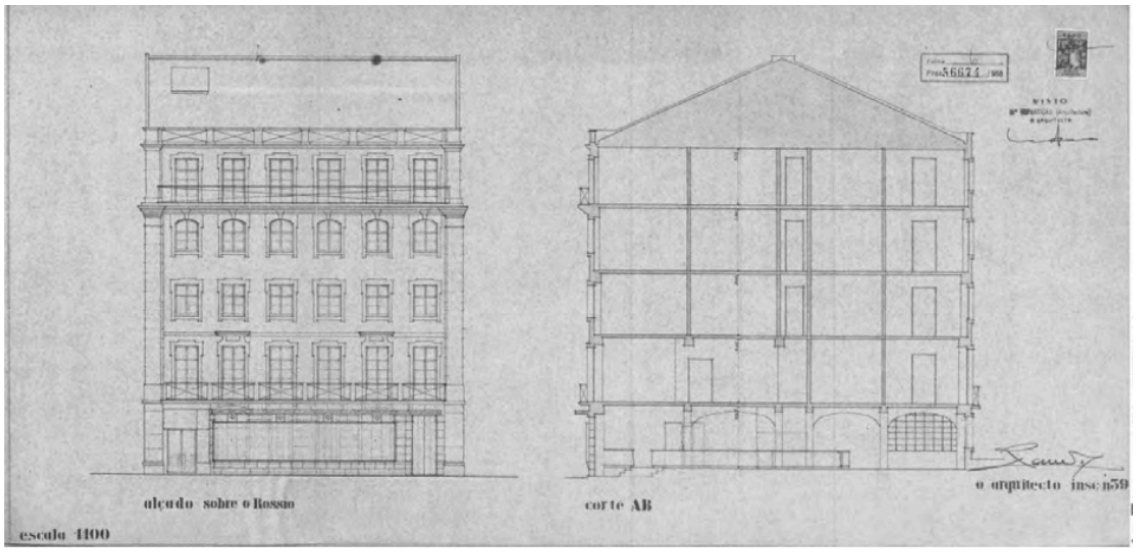


Figure 5.03 – Approval of openings at ground floor: building permission of CML (AML, PO 20631, 1955, folha 6)

(ii) *owners and/or users (decision-makers)*: It should be stressed that among multiple stakeholders involved in the rehabilitation process of the *Pombalino* buildings, their owners (in most cases private companies, banks/insurers)[19] are the most influential decision-makers (*Figure 5.02b*). In fact, the main solutions, including the choice of materials/techniques and the type of reuse, are typically dictated by owners' preferences.

[18] Ranging from unplanned to planned, maintenance could be distinguished into deferred, emergency, corrective, general, preventive, predictive, and proactive actions.

[19] The current policy underway is the disposal of unused buildings belonging to public authorities. In addition, other incentive plans are recently introduced for fostering the urban renewal, e.g. *Rehabilitate First, Pay Later* which defers the date when the price of the building must be paid to Lisbon Council until the end of the contractual term (no. 348/2012).

Budgetary constraints and/or limitations due to the occupancy of owners or tenants (e.g. cadastral situation, use, and access system) are the key influential factors on the interventions on these buildings that are discussed below (*Figure 5.02b*). Workers, material costs, and the time required to implement the interventions are primary considerations in the selection of the rehabilitation solution. These and other budgetary constraints strongly influence the decision: solutions that call for time-safe and non-specialised workmanship are typically preferred by the decision-makers because they would guarantee a fast return on investment. Despite their importance, the different technicians employed (architects, structural engineers, designers) constitute a very low percentage of the total cost of the rehabilitation. This presents a situation in which technicians are not being compensated adequately for their expertise, or in which less-qualified technicians are being chosen for employment.

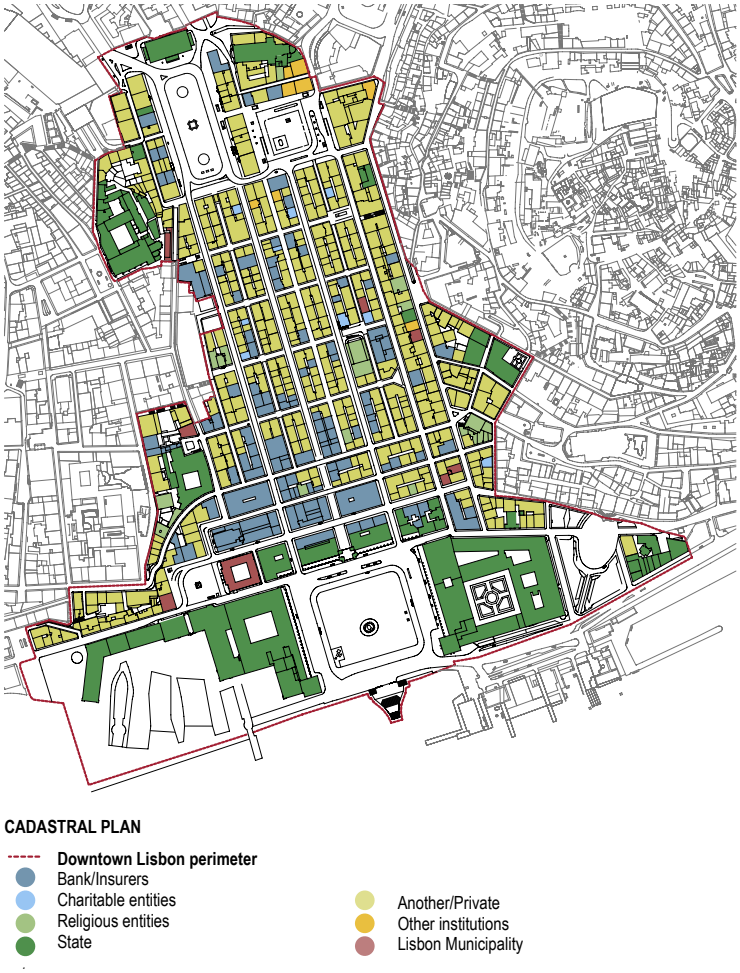


Figure 5.04 – Ownerships of buildings in downtown Lisbon, adapted from (CML 2011b, ploatbord no.10)

If budgetary constraints and/or restrictions derived from the occupancy of the building plots prevent a single-stage intervention, a multi-stage project that manages the available budget over a limited time can be a successful strategy. A sequence of planned rehabilitation actions falls into the category of *incremental rehabilitation*, whose advantages from a cost/benefit analysis are shown in some reports by the U.S. *Federal Emergency*

Management Agency (FEMA).[20] Beyond economic constraints, neighbours' ownership rights must also be taken into account. Due to the specific features of these buildings **–** structural continuity of the timber skeleton, alignment of the internal openings and vertical structures **–** intervention strategies would be more effective in cases where there is a sole proprietor or all the owners agree to a common intent. The reliability of the intervention suffers when multiple owners fail to form an integrated plan, which presents difficulty in assessing and improving the seismic behaviour of the contiguous building units. Apart from the cadastral situation, another aspect to be taken into account is the use. It should be noted that the majority of the interventions in recent years are devised to convert the upper floors of these buildings into apartments and tourist accommodations. It is possible in theory for the adaptations[21] to the original layout and the loading conditions to be compatible with the original configuration, the structural model, and compartmentalization of the interior space. Santos alleges that two qualities of this type of buildings are their versatility of use and the possibility to introduce new facilities in order to meet the new standard requirements with relevant economic and social benefits.[22]

Conversely, if the intervention strategies are devoted to maintaining the original use **–** a housing entrance or store on the ground floor and residential units on the upper floors **–** the original layout is frequently changed. This contradiction can be explained by the current preference for large spaces (i.e. non-compartmented interior spaces with large dimensions), in contrast with the original layout composed of very regular and small/medium compartments. Another crucial issue regards the installation of lifts, the execution of which is hampered by the small floor area at the entrance to the building. It is also important to consider the increase of stiffness and its resulting impact on the overall behaviour of the construction.

(iii) *technicians*: Technicians should be mediators between decision-makers, public institutions, and builders (*Figure 5.02c*). They are required to present the decision-makers with solutions that meet code-required actions (e.g. removal of architectural barriers, improvement of minimum indoor comfort conditions, structural upgrading), accomplish functional alterations, and pursue aesthetic preferences as well. These practical solutions should be implemented with an eye towards advantages for the community and the building itself in the long term.

The most common problems facing the technicians are the lack of skilled workmanship, insufficient knowledge about the compatibility between traditional materials and modern solutions, and low financial and technical support by the municipality (or other public authorities).[23] The selection of a specific intervention strategy among a large number of operational solutions currently tends only to seek a compromise between economic and execution feasibility, leaving aside questions related to the physical conservation of the historic building and its components. A knowledge transfer between the scholarly community and the agents of the property market, as well as the awareness of the community, are crucial to solve some of these questions, as promoted by FPS COST (European Cooperation in the field of scientific and technical research) Action FP1101.[24]

[20] FEMA was founded in 1979 with the aim to prevent, mitigate the effects, and recover from all disasters, natural or man-made, including earthquake damage (www.fema.gov/earthquake) (FEMA 1997) (FEMA 2014).
[21] see *Appendix D.1*
[22] (Santos, M.H. 2000, 182)
[23] (Pedro, J.B.; Campos, V. 2016, 256)
[24] (D'Ayala, D.; Tsakanika, E.; Descamps, T.; Lanata, F.; Kurz, J. Harte, A.; Branco, J. Quinn; N. 2015)

5.2.2 Current legislative and policy instruments in Portugal: some controversial aspects

The rehabilitation of the existing stock may contribute to the cultural and economic development of a country, as highlighted by several scholars and as stated in the regulatory framework at international and national levels. Besides the correlation of economic and environmental developments, the rehabilitation of existing buildings also encompasses questions related to sustainability, such as the minimization of the consumption of energy and materials in comparison to new constructions. Another important aim is improving citizens' quality of life.

For these reasons (e.g. improvement of social well-being, sustainable economic development), the Portuguese construction sector has undergone a shift in interest away from new constructions toward the rehabilitation of existing buildings (though still at a lower level and with some delay in comparison to other European countries).[25] Because this trend is expected to continue, it is worth discussing the appropriateness and effectiveness of the national regulation system: building codes and the building control system (i.e. building control by local authorities).[26]

A comprehensive overview of the Portuguese building regulation system was provided in 2009 in the project entitled *Research for the built environment* (OTB) born from the collaboration of researchers from TU Delft and LNEC.[27] The OTB report shows that the current Portuguese legislative framework *on this issue* was conceived as the implementation of the European Directives and has been considerably simplified in recent years in order to expedite and promote rehabilitations of disused (or severely damaged) buildings. Moreover, the increased delegation of responsibility to private agents – designers and inspectors – for compliance with building regulations may overcome the greatest limitation of *these* processes: the lack of municipal technicians in number and preparation.[28]

The legal basis of Portuguese practice is the *Regulamento Geral das Edificações Urbanas* (*RGEU*)*,* dating from 1951[29] and updated with minor amendments after numerous requests by technicians belonging to the professional associations of engineers and architects. Interestingly, in spite of demands for a standardised and coherent legal framework, a comprehensive review of the *General Regulation of Urban Building* has still not materialised. The question has been provisionally addressed by the decision to draw up a set of Portuguese legal provisions every year. Project solutions are expected to comply with the up-to-date decree-laws that are available on the municipalities' web sites. What results is a fragmented, tangled, and contradictory legislative framework that demands the involvement of various authorities (the Ministry for Public Works, Transport, and Communications and the Ministry of Economy) to address the preparation of the national building regulations within their specific disciplinary areas.[30]

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[25] Through an analysis of the building rehabilitation of the countries belonging to *Euroconstruct*, it should be noted that European productivity average in this segment is 34.9%, whereas in Portugal in 2011 reaches a value 26.1% and in Italy amounts to 52.5% (Euroconstruct 2012).
[26] (Pedro, J.B.; Campos, V. 2016)
[27] (Pedro, J.B.; Meijer, F.; Visscher, H. 2009). The main goal of this research project is the description of the building regulation system in 35 European countries (first phase, 2007-2008), followed by a comparison of these cases and trend analysis (second phase, 2009). The merits of OTB research are in contextualizing the Portuguese building regulation system by discussing the main contradictions and limitations.
[28] (Decree-Law 1970) (Decree-Law 2007)
[29] (Decree-Law 1951)
[30] (Pedro, J.B.; Meijer, F.; Visscher, H. 2009, 159)

A brief critical discussion of the two-fold regulation shall now be provided, first regarding the national legislative provision in effect from 2014 until 2020 for historical buildings within areas zoned for urban renewal (as designated by the municipalities). Second are the municipal regulations valid for downtown Lisbon, focusing on the structural safety requirements (or lack thereof) and how this negatively affects current practice.

Following the establishment of eleven *Sociedades de Reabilitação Urbana*[31] (SRU) in Portugal, the building regulations enacted in 2004 provided special funding for the renewal of specific critical urban areas, including the rehabilitation of historic buildings in those areas. Ten years later, updated building regulations were approved by the Portuguese Government, which established an exceptional legal framework for the rehabilitation of all more-than-thirty-year-old constructions nationwide[32]. In line with a general principle of preservation, this framework derogates specific requirements that would otherwise be imposed for new constructions in terms of habitability, accessibility, acoustic requirements, energy efficiency, thermal quality, and regulations related to other new installations and facilities. This amounts to a form of deregulation promoted by the Portuguese Government, to which the professional and scientific community and associations are much opposed, seeks to address the need to recover a large number of historic buildings following a long stagnation of the real estate sector. In addition, the aim is to reduce the time and cost of excessive bureaucracy, and to abrogate unnecessary regulatory constraints.[33] Existing constructions built before the approval of this law (25% of the overall stock) are exempt from this regulation so long as minimum levels of safety, comfort, and accessibility are guaranteed and there is no downgrading from the status quo after the building interventions (article 9).

As recently underlined by the scientific community, the opportunity to set up an effective strategy for mitigation of seismic risk was therefore ignored by this government initiative. This is a missed opportunity; moreover, the dynamism of the building sector is counterproductive in the long term unless it is accompanied by an informed sensitive operational process; the absence of a restrictive policy related to structural safety requirements leaves contractors and builders to act at their own discretion, without concern for seismic vulnerability.[34]

We analysed the Portuguese housing stock in the 2011 census,[35] which catalogues the variety of types of structure (and levels of seismic resistance) and different maintenance conditions in buildings of the same construction period (*Figure 5.05*). The first relevant information from 2011 census regards the low ageing index of buildings: the national building stock is relatively young, as stated also by *Housing Statistics in the European Union* (2010). In 2011, 61% of the surveyed buildings were built after 1970, while the percentage corresponding to a construction period prior to 1919 decreases to 6%.

The seismic resistance of the buildings erected prior to 1946, made of masonry walls (or mixed walls) and timber floors, is evaluated with poor or very poor performance; these require more extensive intervention rather than post-1952 constructions, which had to comply with demanding safety requirements at the time they were built.[36] However, *Pombalino* buildings typically behaved better than other constructions in the category of building stock prior

[31] Authorities for urban rehabilitation
[32] (Decree-Law 2014)
[33] (Pedro, J.B.; Campos, V. 2016, 257)
[34] (SPES 2012)
[35] (INE 2011)
[36] (Pedro, J.B.; Campos, V. 2016, 256-257)

to 1946, especially if the structural system was not heavily modified and the building pathologies had been prevented and controlled in the meantime.[37]

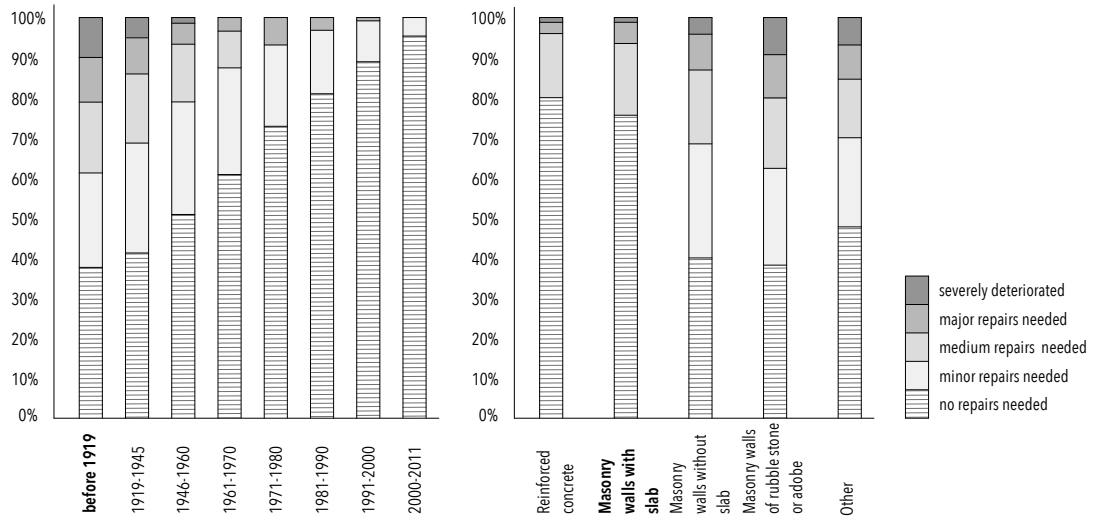

Figure 5.05 – Maintenance condition of residential buildings per construction date and per type of structure, adapted from (Pedro, J.B.; Campos, V. 2016, 255)

Similarly to the Italian framework, the building permit procedure for existing buildings in Portugal depends on construction type and location, as well as on the proposed function, which can require compliance with specific regulations in terms of load capacity and structural safety. In Portugal, building permit procedures are not mandatory in the following situations: (i) ordinary maintenance of the interior with no significant changes in the overall structure or in the external enclosure (e.g. facade and/or roof); (ii) intervention with no or low impact on the urban setting; and (iii) public ownership of the building.[38]

Conversely, the building notice procedure[39] is required in cases of: (i) internal demolitions, even when the preservation of the facade is intended; (ii) changes of use and structural layout; (iii) alterations of the facade within a historic urban area or subject to a local development plan; and (iv) other cases, e.g. the introduction of particular activities.

With regard to the regulations for structural safety, there is no consensus on what level of performance must be reached. In addition to the Portuguese regulations, useful standards for mechanical resistance and structural stability are provided by Eurocode 1998-1, which are performance-based regulations,[40] unlike the Portuguese regulations.

Historic buildings that are of remarkable architectural value or that are located in downtown Lisbon are subject to a building control system that is more restrictive than the building notice procedure. A permit procedure has to be applied and the compliance of all technical aspects of the engineering design also have to be checked.

[37] see *Chapter 4*, *section 4.4.3*
[38] (Decree-Law 2007)
[39] Detailed design and engineering plans are not mandatory in the building notice, but only a check and the approval of administrative aspects and of the architectural plan.
[40] (EN 1998) (EN 2004a) (RERU 2014)

Apart from the need to safeguard the historic centre,[41] special attention to the seismic safety of the built assets is required due to the vulnerability of the hydrogeological conditions of this area. This aspect is unfortunately overlooked in the current practice.[42]

The first legal measures related to the safeguarding of Baixa Pombalina date back to 1978, when the historic district became listed as a Public Interest Building (Decree Law 95/78 of 12 September 1978, art. 2), treated as a single monument with implications for interventions within its area.[43] At the end of the seventies and during the early eighties, the national urban rehabilitation programs (e.g. PRID replaced by PRU[44]) aimed to support the municipalities at the economic and technical levels by embracing rehabilitation of not only the single monument but the whole housing enviroment. Later, following the integrated planning actions for urban revitalization and restoration of buildings in the adjacent district, *Baixa Chiado* (2007),[45] a municipal plan for *Baixa Pombalina* was adopted in 2011.[46] The first important requirement prescribed in this municipal plan is the prohibition of any alteration of the original main facade, e.g. the enlargement of openings at the ground floor or in the other floors. Previously-approved solutions that had modified the original composition have to be reversed, for example, through the reconstruction of the demolished wall (called *nembo*)[47], as shown in the executed project in *Figure 5.06*. Replacing recently-created door/window openings (voids) with a wall structure (full) satisfies both formal and structural safety requirements.[48] In fact, the original layout of *Pombalino* buildings entails a regularity of the layout, disposition and geometry of each component as previously discussed.[49] In order to achieve a symmetric and balanced configuration, maintaining vertical alignment of the openings in the external facade and in the interior space is an important principle. The mechanical behaviour of the external masonry wall is based on the gradual transfer of the loads from the upper levels to the foundations by the compression of the resistant sections. The transfer of loads occurs in the filled parts of the facade walls.[50] However, it should be noted that there is no specific legislative recommendation about the construction techniques or materials to be employed.

Another noteworthy aspect regards the thoughtless introduction of new window dormers (águas-furtadas), whereas the original layout provides them in alternating rhythm with the openings in the facade of all floors.[51]

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[41] (Almeida, I.M. 2004) (Gonçalves, P.; Bugalhâo, J. 2004)

[42] (Silva, V.; Crowley, H.; Varum, H.; Pinho, R. 2015)

[43] The belated recognition of Baixa Pombalina (proposal in 1970 concretised eight years after) followed França's research, whose first version was published in 1965. Previously, Praça do Comercio was extemporaneously declared National Monument with the Decree on 16 June 1910 (CML 2004, 6-17).

[44]PRID and PRU stand respectively for *Programa para a Recuperação de Imóveis Degradados* (Program for the Recovery of Degraded Property) and *Programa de Reabilitação Urbana* (Urban Rehabilitation Program).

[45] (CML 2006)

[46] A protocol was signed between Lisbon Municipality and other public authorities, such as the *Direção-Geral do Património Cultural* and the *Direção Regional de Cultura de Lisboa e Vale do Tejo* (DRCLVT) (CML 2011b).

[47]An emblematic case study is the demolition of four out of five *nembos* at the ground floor in the building in *Praça D. Pedro IV* nos. 45-50 and in *Rua Primeiro de Dezembro* nos. 66-76 (AML, PO 20631, 1955, folha 6).

[48] (CML 2011b, 12-21)

[49] *Chapter 4, section 4.3*

[50] (Mascarenhas, J. 2004, 97)

[51] Some exceptions can be encountered in the drawings of *Cartulário*, where the window dormers are aligned to all openings of the facade (e.g. elevations nos. 9 and 23), or according to this sequence (where A indicates the presence of the window dormer and B its absence): B-A-B-B-A-B-B-A, mirrored on the other half of the facade (e.g. elevation no. 34) (Viegas, I.M. (ed.) 2006).

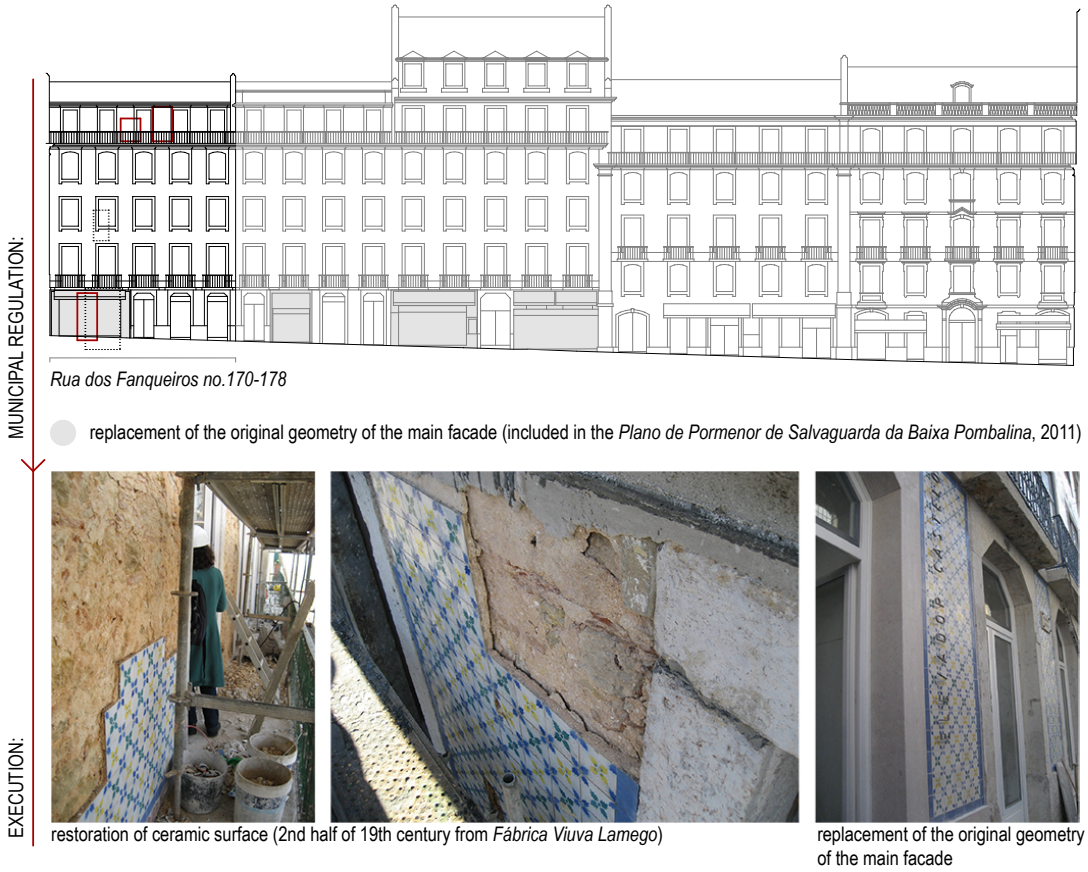

Figure 5.06 – Execution of municipal provision in the building block in *Rua dos Fanqueiros*, adapted by (CML 2011b, Annex 1, drawing no. 35) (top); facade of *Elevador do Castelo* during its rehabilitation works (bottom)(photos from AML, PO 32581, 008/CP/DEPS/N.D./2011)

The repair of the ceramic surface (*revestimento em azulejos*) is also mandatory.[52] In fact, even if tiles, whose expressiveness was generally lower than the former panels during João's reign – were introduced in a second phase (from the second half of the 19th century) the importance of their safeguarding is unanimously recognized. Aguiar reminds us of the importance of conserving the azulejos as distinctive expressive elements, which are also relevant for chemical and mechanical resistance:

"This great popularity of the tile resulted from a close alliance between its high expressive power – establishing new dialogues with a generally humble and restricted urban architecture – and its construction and economic effectiveness. The tile provided new assumptions of architectural expression, more pluralistic and individualized, desired by the new, prosperous and eclectic nineteenth-century bourgeoisie. Its application would extend to later 'rehabilitations' of buildings constructed many years before, as for example some buildings of Baixa Pombalina."[53]

[52] *Regime Municipal de Urbanização e Edificação de Lisboa*, in effect 16 April 2013.

[53] "Esta grande popularidade do azulejo resultava de uma íntima aliança entre o seu elevado poder expressivo – estabelecendo novos diálogos com uma arquitectura urbana em geral humilde e contida – e a sua eficácia construtiva e económica. O azulejo fornecia novas hipóteses de expressão arquitectónica, mais pluralista e individualizada, desejada pela nova, próspera e eclética burguesia de novecentos. A sua aplicação estender-se-á,

Another critical point regards the underground floor of these buildings. The prohibition to modify or enlarge the floor area beneath the street level[54] is justified by the ground conditions: the seismic vulnerability of the soil varies from very high to medium, depending on the local features of the ground – soil flooding and landfill with elevated water level (*Figure 5.07*) – and the high vulnerability to any rise in sea level (SLR).[55]

As shown in the literature, ground conditions strongly influence the propagation of earthquake vibrations at the surface and thus the seismic resistance of the building. Shaking within certain spectral characteristics produces different effects depending on the type of construction, but evidence confirmed by instrumental methods (e.g. response spectra analysis) shows that buildings of the same type of construction system suffer also different levels of damage within a few tens or hundreds of meters, owing to the different characteristics of the subsoil.[56]

Various underground storehouses exist as results of alterations of the original construction model.[57] In the case of a new intervention on a building that includes underground levels, the *status quo* should be studied and the overall structure should be reinforced if necessary.

In the case of other subsequent structural alterations that for example induce a soft storey effect (i.e. absence or lack of interior shear walls generally on the ground floor or the excessive slenderness of the columns, large open spaces with concentration of mass above due to the additional floor to floor height), specific strategies should be planned in order to guarantee a minimum target safety level by increasing the stiffness of the building on the ground floor. In fact, when the ground floor (or the lower part of the construction) supports a massive multi-storey building, the seismic forces will produce larger relative displacements between the ground floor and the floor of the soft story until the building collapse.

Conversely, other structural alterations in this building stock are hardly resolvable. Although they imply an increase in mass, it is highly improbable that extra floors or additional volumes will be demolished.[58] In a few other cases, the current municipal plan permits owners to overcome high dissymmetry in elevation between two adjacent building units by constructing additional floors.[59]

em 'reabilitações' sucessivas, a edifícios construídos muitos anos antes, como por exemplo alguns edifícios da Baixa Pombalina"(Aguiar, J. 1995).

[54] (CML 2011b, art. 27, 4g)

[55] Scenarios of climatic change on Lisbon waterfront are discussed by (Costa, J.P.; Sousa, J.F.; Silva, M.M.; Nouri, A.S. 2014)

[56] (Capotorti, F.; Monachesi, G.; Mucciarelli, M.; Sanò,T.; Trojani, L. 1996) (EN 1998)

[57] *Rua dos Sapateiros* nos.12-22 (AML, PO no. 36658)

[58] see *Table 5.02*, *section 5.3.3*

[59] Further possible additions of extra floors that could be authorised are listed in (CML 2011b, art. 21, 5).



Figure 5.07 – Extract of Lisbon map. Seismic Vulnerability of the soil, adapted from (CML 2006)

It is relevant to note the difference underpinning the municipal provisions for external configuration, which is characterised by a conservative approach, in contrast with permissiveness for more intrusive intervention in the interior layout. When the state of conservation is deemed unsatisfactory or the architectural features are not considered important for safeguarding,[60] the municipal plan goes so far as to approve demolition of the interior in pursuit of improved living conditions.[61]This approach is contrasted by international recommendations: "The value of architectural heritage is not only in its appearance, but also in the integrity of all its components as a unique product of the specific building technology of its time. In particular the removal of the inner structures maintaining only the facades does not fit the conservation criteria".[62]

It is also relevant that the rehabilitation techniques of existing structures are much less regulated in codes or guidelines when compared to the design of new structures. Harmonisation and updating of European technical provisions is overdue,[63] especially regarding timber-framed buildings, which exist in analogous forms across multiple countries, e.g. Portugal, Italy, Turkey, and Greece. Furthermore, if seismic mitigation risk measures are not included, building rehabilitation is a questionable economic investment at the national level. These recent works also convey an untruthful perception of safety to owners and users.[64]

[60] "Nos edifícios cuja tipologia interior não apresente valor histórico e artístico, e/ou cujos elementos apresentem degradação irreversível, são autorizadas obras de alteração total para reabilitação funcional" (CML 2011b, art. 27, 3).
[61] (CML 2011b, art.19)
[62] (ICOMOS 2003b, criterion 1.3)
[63] (Catarino, et al. 2016, 242)
[64] (Pedro, J.B.; Campos, V. 2016, 259)

5.3 Rehabilitation of historical timber-framed buildings

A critical understanding of the most appropriate interventions on historic buildings must include acquaintance with the building in question, the context it is situated in, and the issues outlined in this section: guidelines for the safeguarding and strengthening, impact of repair or strengthening works on timber frame walls, and the main vulnerabilities of these constructions.

5.3.1 Main principles of interventions on historical buildings

Essential requirements for interventions on traditional construction systems can be found in international guidelines and charters for the safeguarding of architectural heritage[65] and they can be summarized as follows:

- low intrusiveness with distinguishability;
- physical, mechanical, and chemical compatibility with the original materials;
- seismic upgrading by compliance with *a reasonable equivalent safety*.

(i) A surgical approach is preferable, since uncertainty stemming from the level of knowledge of the existing constructions and the reliability of the current practice should be a deterrent for intrusive solutions.[66]

Less intrusive interventions, which involve a minimization of loss of the original material and maintenance of the original structural model should be privileged over any other solutions. The interventions should also fulfil the requirement of low visual impact.[67]

The replacement parts should integrate harmoniously with the whole in terms of the material, design, species[68], grade, slope of grain, dimensional stability, and decay resistance of the original components as closely as possible. This means that the interventions should follow traditional means.[69] It should be also emphasised that it is very common to find second-hand timber from other buildings and different wood species in the same timber frame walls or wooden joists.[70] The re-use of old wood in repair works is an option in line with eco-sustainable development strategies; although some frown upon this for moral and practical reasons, a number of firms are devoted to supplying old timbers.

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[65] The extensive discussion on the leading principle related the safeguard of the built heritage goes beyond the research target. However, milestones can be found in several international bodies (ICOMOS 1999) (ICOMOS 2003a) (ICOMOS–ISCARSAH 2004) (UNESCO 1972) (UNESCO 2005) and national heritage recommendations (Cruz, et al. 2015).

[66] (ICOMOS–ISCARSAH 2004)

[67] However, it should be noted that Tampone warns us about the risks of hiding structural failures and the necessary repair interventions, with the aim of preserving the visual appearance of the original structure (Tampone, G. 1996).

[68] "As each species has its own specific physical properties, using the same kind means that the replacement parts will behave in the same way as the original material" (Larsen, K.E.; Marstein, N. 2006, 8). Additionally, the use of the same wooden species leads to match the aesthetic appearance between the old and replaced components.

[69] Wood Committee's Principles, art. 5 (Larsen, K.E.; Marstein, N. 2006, 31)

[70] The re-use of raw materials in *Pombalino* buildings may be indicated in archival documents or may be deduced from frequent mismatches between the carvings of the wooden components (previously notched to other components of the skeleton) or the heterogeneity of infill. A building contract of 1776, for instance, interestingly reports the provenience of the wood – oak or Brazilian wood from a dismantled ship (Penn, R.; Wild, S.; Mascarenhas, J. 1996, 15).

At the same time, the distinguishability of the intervention (art. 12, Venice Charter) is guaranteed by the regularity of the replaced components in geometry, grade, type of assembly and by their different colour, dimension and types of defects (e.g. knots, bark inclusions or cracks). New wooden members should also be identified by simple carved inscriptions to indicate the date of the execution, as stated by the Wood Committee's principles.[71] In general terms, artificial patina or other methods to match the colouring aimed to achieve the harmonisation between the old and new components are not recommended.[72]

The conservative approach includes the minimum replacement of original materials (i.e. decayed timber elements or missing/damaged infilling materials) with similar new ones. This is the oldest approach, deeply rooted in the vernacular architectural culture.

In some contexts, however, the significance of the construction should be handed down by safeguarding its meaning, regardless of the permanence of the material artefact itself.[73] In Japan, the physical space is still conceived as a practical sphere to project the essential values of the meaning and its use. The safeguarding of the immaterial value of the local crafts and thus the preservation of the spirit of place[74] is achieved though steady monitoring and formal reconstruction, even up to the point of arriving at a complete replica, as occurred in the Golden Hall (Kondo) of the Horyu-ji Buddhist temple in Nara.[75]

(ii) Secondly, the concept of reversibility, following the recommendations of the Venice Charter, has today been supplanted by those of compatibility and retreatability. In fact, the seismic retrofitting of mixed systems made of wooden components or the impregnation of a product within the porous network of mortars is not reversible.[76] Compatibility requires that materials used for the treatment do not have negative consequences (e.g. harmful chemical reactions or formation of by-products), whereas retreatability implies that the present conservation treatment will not preclude or impede future treatments.[77]This principle can be intended as acknowledgement of the fallibility of our work.[78] A general, even vague, prohibition of the use of non-compatible materials or techniques is included in the municipal legislation for downtown Lisbon: "the introduction of materials, systems or structural elements which may directly or indirectly, due to chemical or physical incompatibility, cause premature ageing in existing structures, or which transmit incompatible stress with their shape and features, or which may lead to discontinuities of propagation of seismic waves in its constructed surroundings, is not authorized." [79]

[71] (Larsen, K.E.; Marstein, N. 2006, 35)
[72] In Japan, the desired patina can be achieved by means of treatment of replaced wooden components using proper coatings or by burning the surface.
[73] (Larsen, K.E. 1996) (Lipovec, N.; Van Balen, K. 2008)
[74] "The spirit of place embraces the unique, distinctive and cherished aspects of a place, and relates strongly to the sense of place and its impact on identity and sense of belonging" (Lipovec, N.; Van Balen, K. 2008, 7). Lipovec and Van Balen stress how the transmission of technical knowledge (e.g. traditional design and use of local materials) has been lost in the dominant individualistic society, especially in western ones. On the other hand, these scholars underline the risk of excessive maintenance, which may compromise the material authenticity of the historical buildings.
[75] (Larsen, K.E.; Marstein, N. 2006, 15-18)
[76] (Hees, R.; Veiga, R.; Slížková, Z. 2017)
[77] (ICOMOS 1964)
[78] (Cattanach, A.G.; Alley, G.W.; Thornton, A.W. 2008, 6)
[79] "Não é autorizada a introdução de materiais, sistemas ou elementos estruturais que possam influir directa ou indirectamente, por incompatibilidade química ou física, no envelhecimento precoce das estruturas existentes ou

When the wall must be completely replaced due to its poor state of conservation, mechanical compatibility is also an additional requirement. The new components should guarantee the same strength and ductility of the original construction system.

(iii) Considering that Lisbon is situated in a seismic prone zone (Zone A, highest level of seismic hazard, which extends to the south of mainland and its adjacent Atlantic margins)[80] (*Figure 5.07*), design provisions for ensuring acceptable lateral resistance are a priority. Rehabilitation techniques encompass a wide range of interventions that may entail severe impact on the historical building in terms of authenticity, integrity, and structural reliability. Different degrees of structural upgrading can be achieved depending on the type of interventions, defined according to the nominal life of the building and the probability of the occurrence of a seismic event within a period of time.

The assessment of the safety requirements for historical buildings, including the category of timber-framed buildings, is a demanding task whose results are always uncertain to some extent. In line with Giovannoni's thought,[81] it is generally assumed that the safety level should not necessarily require matching that of new constructions. This assumption results from an extensive debate, especially in Italy, where the need to revise rehabilitation practice following various errors has generated a comprehensive legislative corpus[82]. In fact, the conjunction of the unparalleled quantity and value of built cultural heritage and the extent of earthquake damage has impelled Italy to develop pioneering theoretical and operational strategies. After a parenthesis of uncritical enthusiasm for new technologies, such as reinforced concrete, and overcoming the separation between retrofitting and restoration, the analytical and comprehensive vision promoted by De Angelis d'Ossat (1907-1992) seems the right way forward. Only at the end of the 20th century was it understood how the project of reducing the seismic problem should belong to the field of restoration. In particular, explicit opposition to some current design approaches was included in the national provision coordinated by Ballardini (1986), stated by Galli as "the pursuit of a new attitude aimed at combining technical reasoning with historical consciousness".[83] The importance of deep knowledge and recovery of local-technical culture in specific geographic areas was re-evaluated following the research expeditions headed by Marconi.[84]

Beyond the studies of di Pasquale and Benvenuto, the methodological approach developed by Giuffrè in the 1980s and 90s can be considered a forerunner in the debate over interventions of traditional unreinforced structures. This scholar analyses the correlations existing between seismic forces, type of construction, and mechanism of rupture through on-site analysis of the historical built environment. The key idea underpinning Ballardini's provisions is the replacement of the concept of *improvement* by the concept of *adaptation*. *Improvement* entails alteration of the structural behaviour of the building (or its component) whereas the *adaptation* entails only upgrading the building's behaviour in the presence of dynamic stress. *Adaptation* includes every intervention that

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que transmitam solicitações não compatíveis com a sua forma e natureza, ou ainda que provoquem descontinuidades de propagação de ondas sísmicas na sua envolvente construída." (CML 2011b, art. 25, par.6)

[80] (Ferrão, C.; Bezzeghoud, M.; Caldeira, B.; Borges, J. F. 2016)

[81] Because numerical analysis conceived for new constructions has been transposed to historic buildings it implies that the construction principles are not fully understood because "the testing carried out by time" has not been taken into account (Giovannoni, G. 1946, 46).

[82] (D.M.LL.PP. 1981) (MCHA 2007)

[83] (Galli, C. 2013)

[84] (Marconi, P.; Giovanetti, F.; Pallottino, E. (eds.) 1989)

avoids contributing to a collapse mechanism or to the absorption of fracture energy.[85] It should be also noted that the term *restoration* has frequently been discarded and replaced by the term *preservation*.

[85] (Binda, L.; Saisi, A. 2009, 213)

5.3.2 Therapy for historical buildings: repair versus strengthening

A building can be compared to the human body in that neither can be expected to remain unchanged. However, there are relevant differences between medicine and conservation science. Medicine relies on statistical information as a support for understanding phenomena and establishing proper generalisations. In general terms, the therapy proceeds based on factual effects and progressive rehabilitation phases depending on the patient's response. However, in the case of interventions on built heritage, standard technical prescriptions are frequently unsatisfactory due to the uniqueness of the case studies.[86]

Active preservation of the building – as defined by Giuffrè[87] – is essential to keep the construction alive and guarantee its transmission to future generations. Intervention on the constructions can be viewed as a sort of therapy, the third action that follows analysis and diagnosis, in turn followed by the control and the prognosis phases.[88]Therapy aims at solving weaknesses and making the building safer and less prone to major structural damage during earthquakes or other external events.[89]

The dichotomy between *integration* and *integrity*[90] has always been part of historic building rehabilitation and characterises the contemporary paradigm, split between economic interests and conservationist motivations. Conflicting demands, such as the safeguarding of authenticity, practical feasibility, budgetary limitations, and other constraints related to the occupancy of tenants or owners, may intersect when building rehabilitation is underway. The rehabilitation of historic buildings should therefore require a multidisciplinary approach and specific skills to conceive the interventions able to meet contemporary users' requirements without compromising the cultural value of the construction. A wide range of intervention strategies exists, depending on the scope of application and expected results at the global or local level. Definitions of different intervention works can be found in national and international recommendations, such as in Australia's ICOMOS *Burra Charter*, or *Charter for Places of Cultural Significance*,[91] described in *Appendix D.1*.

The key concept of restoration is defined in *Webster's New Collegiate Dictionary* (1975) as "a bringing back to a former position or condition." Later, it is specified that restoration works involve a return to the original configuration "by reassembling existing components without the introduction of new material".[92]

As a preliminary approach, the set of possible interventions is indicated in *Figure 5.08* – a graph that correlates the ageing of historic building to its economic and functional value, which depends on reliability or compliance with minimum safety requirements. The first thing one notices is that the lifetime of the historical building

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[86] (Bardelli, P.G.; Ribaldone, M. 2009, 24-25)
[87] Seismic improvements arise from an in-depth knowledge of the construction features and the original mechanical features of the building (Giuffrè, A. 1988) (Giuffrè, A. 1995).
[88] Anamnesis, diagnosis, therapy and controls, corresponding respectively to the searches for significant data and information, individuation of the causes of damage and decay, choice of the remedial measures and control of the efficiency of the interventions (ICOMOS 2003b). See (Carbonara, G. 1997).
[89] (Schueremans, L.; Verstrynge, E. 2008)
[90] "Integrity is a measure of the wholeness and intactness of the natural and/or cultural heritage and its attributes. Examining the conditions of integrity, therefore requires assessing the extent to which the property: a) includes all elements necessary to express its outstanding universal value; b) is of adequate size to ensure the complete representation of the features and processes which convey the property's significance; c) suffers from adverse effects of development and/or neglect" (UNESCO 2005). See (ICOMOS 1964) (Jokilehto, J. 2006) (Stovel, H. 2007).
[91] It was adopted in 1979 and amended in 1981, 1988, and 1999 (ICOMOS 2003a).
[92] (ICOMOS 2003a, art.1, 1.7)

can be represented as a decreasing function similar to the human cycle, since its state deteriorates with the passage of the time.

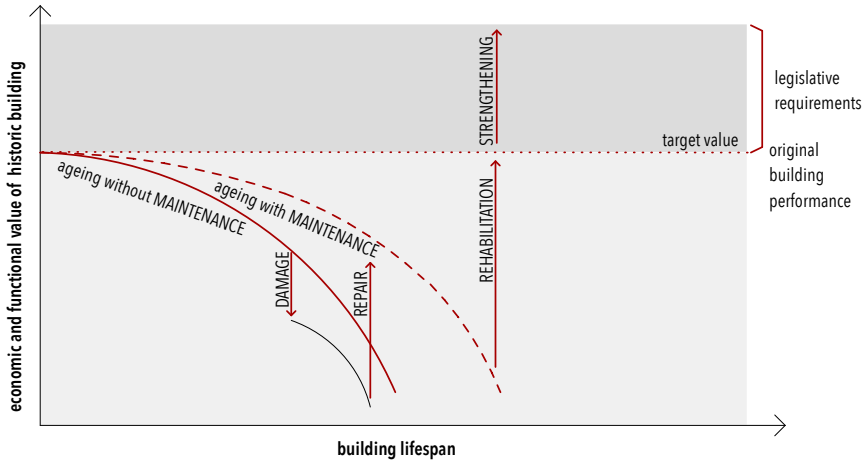

Figure 5.08 – Economic and functional value of historic building and its lifespan (© S. Stellacci)

A countermeasure for ageing is routine maintenance:[93] if there are proper maintenance and rehabilitation works, the value of the building may increase to the target level established by the current legislative requirements. Conversely, less frequent yet more extensive interventions may entail major costs and also undermine the viability of the conservation project.[94] The definition of the main aim of the rehabilitation works is a crucial step. The difference between *rehabilitation* and *strengthening* is marked by the red dotted line in *Figure 5.08*.

Rehabilitation means returning as closely as possible to the original building performance, whereas *strengthening* is improving its resistance capacity beyond that point. Conservative repair implies preserving the original structural layout through the use of compatible products and techniques, i.e. with similar physical-mechanical features, and avoiding harmful chemical reactions or by-products. Conversely, slightly more intrusive interventions address the structural features with the main aim of meeting higher target reliability levels of the structure.

Repair is part of the conservation process of a structure and its aim is to preserve the structure by correcting existing damage and preventing further decay. *Strengthening* implies adding something to the structure modifying the original performance and layout of the structure.[95] The problem is that evaluation criteria to judge the most suitable level of a structural improvement can be subjective, also due to congenital uncertainty of the behaviour of traditional mixed constructions.

[93] A definition of routine maintenance is provided in the Strategic Plan for Preserving Iowa's Buildings and Monuments: "expenditures made for the regular upkeep of physical properties (i.e. Land, Buildings, and Equipment) including recurring, preventive and on-going maintenance necessary to delay or prevent the failure of critical and non-critical building systems and equipment. For purposes of this definition, building operational costs are not considered routine maintenance" (Iowa's Vertical Infrastructure Advisory Committee 2011, 2). The routine maintenance includes: "Other activities planned and performed at regular intervals normally established by manufacturers or associations and based on testing or other evidence indicating the maintenance work is necessary to extend the life or prevent the premature failure of building components or equipment". (Ibid.)

[94] Integrated conservation as enshrined in 1975 in the European Charter for Architectural Heritage of the Council of Europe (Lipovec, N.; Van Balen, K. 2008) (Schueremans, L.; Verstrynge, E. 2008, 1321).

[95] In every strengthening measure, a preliminary estimation of dimensions of additional structural parts and of the modified stiffness of the retrofitted elements is required, as stated in Eurocode 8 (EN 2004b, 34).

5.3.3 Interventions on timber-framed buildings in seismic prone areas

Interventions on historical or existing constructions in seismic prone areas are scarcely regulated at a European level, even though national provisions have been settled in various countries. Reference on seismic design codes can be found in Italy (e.g. OPCM 3274), whereas in Germany – even if it is a low-seismicity area – specific regulations exist for the maintenance of existing timber-framed buildings and, additionally, a multi-disciplinary organization strives to preserve this built heritage.[96]

Thus, in the absence of a consistent European legislative framework, seven types of seismic upgrades as defined by FEMA[97] are below analysed. These intervention categories indicated in *Table 5.02* are evaluated in reference to the *Pombalino* buildings by Cóias, taking into account budgetary and feasibility constraints .[98]

Table 5.02 – Intervention strategies on *Pombalino* buildings, data from (Cóias, V. 2007, 155)

Intervention strategy	Solutions for *Pombalino* buildings	Advantages	Limitations
1) Local modifications of the original configuration or 2) Removal or minimisation of existing irregularities and discontinuities	a) Demolition of extra (new) storeys;	Maintenance of original layout; safeguarding of building's architectural value	Inconvenience to users; reduction of floor area; requires high level of workmanship; decrease in financial value
	b) Removal of incompatible elements, e.g. elevator shafts, concrete slabs, overhanging or inappropriate structures (rear facade)		
	c) Removal of (new) openings and alterations in the interior layout		
3) Global structural stiffening	a) Stiffening timber frame walls and floors		Inconvenience to users; high level of workmanship; reduction of floor area
	b) New walls or structures		
4) Global structural strengthening	a) Strengthening with composite materials, without modifying the geometry of the walls or increasing their weight		Requires high level of workmanship
	b) Partial grouting with reinforced concrete		
	c) Local strengthening (e.g. connections of the timber elements and of the masonry walls)		
	d) Closure of openings by precast cement elements	Practical feasibility	Alteration of original configuration; increase in mass
5) Mass reduction	a) Demolition of additional storeys or removal of non-traditional partitions		Inconvenience to users; reduction of floor area; decrease of the financial value
	b) Removal of heavy furnshings		
6) Seismic isolation	a) Inserting compliant bearings between the superstructure and the foundation	Reducion of seismic impact on structures	Excessive cost; requires high level of workmanship; low effectiveness for light and flexible components
7) Supplemental energy dissipation	a) Special devices for isolation for ground shaking	Maintenance of original layout, safeguarding of building's architectural value	Requires high level of workmanship and cutting-edge methods
	b) Seisimic dissipator devices for walls		

Global structural strengthening (intervention strategy no. 4) is recommended when the components show inadequate ductility and strength to resist large lateral deformation. As alternatives to strengthening and stiffening, mass reduction, seismic isolation, and supplemental energy dissipation (1a, 5a, 5b) are not considered feasible for this type of construction system. Considering that extra floors in *Pombalino* buildings are fully integrated in the external configuration of the original construction for a number of reasons (e.g. alignment of the openings, roof/dormer geometry, architectural features), their demolition (1a) would incur a loss of the architectural value of the building, as well as a reduction of floor area and inconvenience to the users. This is also incompatible with the decision-makers' interests, due to a considerable decrease in the financial value of the investment.

[96] (OPCM 3274 2003) (ÖNORM EN 1998-1 2011)
[97] (FEMA 1997)
[98] (Cóias, V. 2007, 154-157) (Ferah, F.E. 2009)

5.3.4 Overview of rehabilitation techniques for traditional timber frame walls (TFW)

This work regards TFW determined as retrofittable through visual grading and non-destructive testing (NDT). As a precondition for being repaired or strengthened, the timber framework will guarantee some residual capacity if the level of conservation, the effective cross-section, and deformations are acceptable. It should also be pointed out that all interventions involve the removal of the surface finish, which should be preceded by a detailed documentation of the pre-intervention status quo.[99]

A set of specific interventions was identified for each of the four sub-components: timber framework, infill, joints, and surface finish (*Figure 5.09*, *Table 5.03*, *Appendix D.2*).

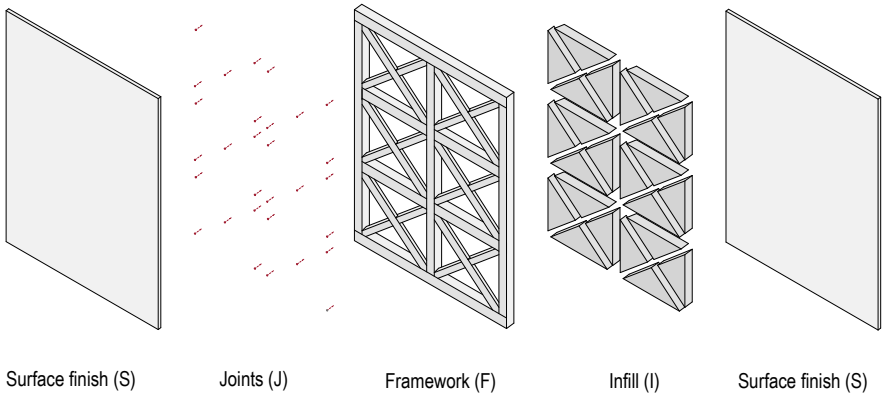

Figure 5.09 – Sub-components of timber frame wall (TFW) (© S. Stellacci)

Individual options identified for those sub-components were grouped into 131 combinations, which were in turn divided into eleven groups according to the type of the intervention on the wall structure (*F+I*) (*Tables 5.03*, *5.04*). These 131 combinations were selected with the aim of grouping similar solutions across the sub-components in order to arrive at interventions that would be homogeneous for the whole wall. Such a homogeneous intervention would entail reasonable economic and practical feasibility, i.e. minimum number of material types and skills required in the work site. Advantages and disadvantages of the interventions, details, and predictable failure modes can be derived from an extensive literature review of current practice and experimental campaigns.[100]

In order to streamline the large number of possible combinations, the following separate interventions are equated in *Table 5.04*:

- *F3a* = *F3b*: due to comparable mechanical behaviour.
- *I1* = *I2a*: different mechanical performances of these types of infill (brick or rubble masonry *versus* clay

[99] (ICOMOS 1964, art.16)
[100] The current practice is discussed by national literature but also includes solutions commonly adopted within Greek and Italian timber frame buildings. These broad references are justified by the structural analogies of these construction systems in the Mediterranean basin (Tsakanika-Theohari, E. 2008) (Bianco, A. (ed.) 2010).

bricks or roof tiles) are not significant, since both include (low strength) hydraulic lime mortar,[101] which produces a similar response for the shear transfer mechanism and dissipative capacity.

- *J1a = J1b*: though there were different performance parameters of wooden versus metallic carpentry joints, such as moisture condensation in the timber-steel elements interface and low visual compatibility,[102] these solutions can be equated for similar energy dissipation mechanisms and good ductility. Both dowel-type connections allow a mutual rotation of the elements.

Table 5.03 – Interventions for each sub-components of the timber frame wall (TFW)

Timber frame wall components		Main aim	Sub-Intervention	Description	References
WALL STRUCTURE	FRAMEWORK	Removal of causes of degradation (e.g. corroded iron elements and decayed timber elements) and preservation or reconstitution of the structural continuity of the wall	**F1**	**Removal of decayed timber elements and replacement with autoclaved timber components**	Appleton, 2003; Appleton and Domingos, 2009; Campanella and Mateus, 2003
			F2	**Substitution of decayed timber elements with wooden prosthesis using:**	
			F2a	Structural timber glue	Tsakanika-Theoharis, 2010
			F2b	CFRP or GFRP bars+ Epoxy resin	Pizzo et al., 2004; Cruz et al., 2001; Gonçalves et al.,2014
			F2c	Steel rods + Epoxy resin	Poletti and Vasconcelos, 2015
			F2d	Stainless steel screws	Tsakanika-Theoharis, 2010
			F3	**Introduction of stainless steel structure by using:**	
			F3a	Stainless steel cross-bracing	Appleton, 2003
			F3b	Stainless steel beams/columns with bolted and welded plates	Mascarenhas, 2004
			-	Diagonal damper	Gonçalves et al., 2014
	INFILL		**I1**	**Partial removal of infill and repair of the brick or rubble masonry with natural hydraulic lime mortar**	Appleton and Domingos, 2009; Bianco, 2010
			I2	**Total or partial replacement of the existing infill by using:**	
			I2a	Clay bricks (or roof tiles) grouted with hydraulic lime mortar	Appleton, 2003; Gonçalves et al., 2014; Bianco, 2010
			I2b	Hollow bricks grouted with cement mortar	Appleton and Domingos, 2009
			I2c	Mineral wool	Appleton and Domingos, 2009
			I3	**No infill**	Poletti and Vasconcelos, 2015
	FRAMEWORK+ INFILL		**F4+I4**	**Restoring the wall to its original condition and placement of reinforced rendering**	Appleton, 2003; Appleton and Domingos, 2009; Gonçalves et al., 2014
JOINTS		Local recovery and strengthening of the original function	**J1**	**Recovery of carpentry joints by using:**	
			J1a	Wooden pegs and pins	Tsakanika-Theoharis, 2010
			J1b	Stainless steel nails	Bianco, 2010; Poletti and Vasconcelos, 2015
			J2	**Strengthening carpentry joints by using:**	
			J2a	Stainless steel bolts	Poletti and Vasconcelos, 2015
			J2b	Stainless steel plates with bolts	Gonçalves et al., 2014; Poletti and Vasconcelos, 2015
			J2c	Self-tapping stainless steel screws	Poletti and Vasconcelos, 2015
			J2d	NSM (steel bars or FRP bars)	Cruz et al., 2001; Poletti et al., 2015
			J2e	EBR (GFRP or CFRP)	Cóias, 2007; Poletti and Vasconcelos, 2015
SURFACE FINISH		Protection of the surface wall	**S1**	**Mono or multi-layer plaster by using:**	
			S1a	NHL-based and/or lime-based render reinforced by fiberglass mesh	Appleton, 2003
			S1b	HL or cement-based mortar	
			S2	**Cement-based mortar with metal mesh (or fibreglass) with acrylic (or polymer) render/additives**	Appleton, 2003; Appleton and Domingos, 2009; Gonçalves et al., 2014
			S3	**Lining panels:**	
			S3a	Plasterboard	Appleton and Domingos, 2009
			S3b	Strips of wood with lime-based mortar	Tsakanika-Theoharis, 2010
			S4	**Surface film:**	
			S4a	Transparent scumble glaze	Campanella and Mateus, 2003
			S4b	Coating finish with pigment	

NSM: Near Surface Mounted; CFRP: Carbon Fibre Reinforced Polymer; GFRP: Glass Fibre Reinforced Plastic;
EBR: Externally Bonded Reinforcement; NHL: Natural Hydraulic Lime
text - not included in Macbeth analysis due to its limited application in current practice

These solutions include traditional methods (e.g. local replacement of decayed components by similar ones) to innovative materials (e.g. synthetic resins, fibre reinforced polymers) with forefront methods (e.g. externally

[101] Bricks masonry made with low strength hydraulic lime mortar were employed as infill for the test specimens carried out by (Meireles, H.; Bento, R.; Cattari, S.; Lagomarsino, S. 2012)
[102] (Ceraldi, C.; D'Ambra, C.; Lippiello, M.; Prota, A. 2017)

bonded reinforcements, near surface mounted reinforcements). As regards the prostheses placed to strengthen the timber framework, the materials range from traditional improved elements (treated wooden components) to non-traditional ones (FRP, epoxy resin).

Table 5.04 – Combinations of interventions on timber frame wall (TFW)

Identification	Wall Structure	Joints	Surface Finish
Group 1			
TF01	F1+I1 (*or* F1+I2a)	J1a (*or* J1b)	S1a
TF02			S3a
TF03			S3b
TF04		J2a	S1a
TF05			S3a
TF06			S3b
TF07		J2b	S1a
TF08			S3a
TF09			S3b
TF10		J2c	S1a
TF11			S3a
TF12			S3b
TF13		J2d	S1a
TF14			S3a
TF15			S3b
TF16		J2e	S1a
TF17			S3a
TF18			S3b
Group 2			
TF19	F1+I2b	J1a (*or* J1b)	S1b
TF20			S2
TF21			S3a
TF22			S3b
TF23		J2a	S1b
TF24			S2
TF25			S3a
TF26			S3b
TF27		J2b	S1b
TF28			S2
TF29			S3a
TF30			S3b
TF31		J2c	S1b
TF32			S2
TF33			S3a
TF34			S3b
TF35		J2d	S1b
TF36			S2
TF37			S3a
TF38			S3b
TF39		J2e	S1b
TF40			S2
TF41			S3a
TF42			S3b
Group 3			
TF43	F1+I2c	J1a (*or* J1b)	S2
TF44			S3a
TF45			S3b
TF46		J2a	S2
TF47			S3a
TF48			S3b
TF49		J2b	S2
TF50			S3a
TF51			S3b
TF52		J2c	S2
TF53			S3a
TF54			S3b
TF55		J2e	S2
TF56			S3a
TF57			S3b
Group 4			
TF58	F1+I3	J1a (*or* J1b)	S3a
TF59			S3b
TF60			S4a
TF61			S4b
TF62		J2a	S3a
TF63			S3b
TF64			S4a
TF65			S4b
TF66		J2b	S3a
TF67			S3b
TF68			S4a
TF69			S4b
TF70		J2c	S3a
TF71			S3b
TF72			S4a
TF73			S4b
TF74		J2d	S3a
TF75			S3b
TF76			S4a
TF77			S4b
TF78		J2e	S3a
TF79			S3b
TF80			S4a
TF81			S4b
Group 5			
TF82	F2a+I1 (*or* F2a+I2a)	J1a (*or* J1b)	S1a
TF83			S2
TF84			S3a
TF85			S3b
Group 6			
TF86	F2b+I1 (*or* F2b+I2a)	J1a (*or* J1b)	S1a
TF87			S2
TF88			S3a
TF89			S3b
TF90		J2a	S1a
TF91			S3a
TF92			S4a
TF93		J2b	S1a
TF94			S3a
TF95			S4a
TF96		J2c	S1a
TF97			S3a
TF98			S4a
TF99		J2d	S1a
TF100			S3a
TF101			S4a
Group 7			
TF102	F2c+I1 (*or* F2c+I2a)	J1a (*or* J1b)	S1a
TF103			S3a
TF104			S3b
TF105		J2a	S1a
TF106			S3a
TF107			S3b
TF108		J2b	S1a
TF109			S3a
TF110			S3b
TF111		J2c	S1a
TF112			S3a
TF113			S3b
TF114		J2d	S1a
TF115			S3a
TF116			S3b
TF117		J2e	S1a
TF118			S3a
TF119			S3b
Group 8			
TF120	F2d+I2b	-	S1b
TF121			S2
TF122			S3a
TF123			S3b
Group 9			
TF124	F2d+I2c	-	S1b
TF125			S2
TF126			S3a
TF127			S3b
Group 10			
TF128	F3a (*or* F3b)	-	S2
TF129			S3a
Group 11			
TF130	F4+I4	-	S1b
TF131			S3a

5.3.5 Main vulnerabilities of restored (or strengthened) traditional timber frame walls

The most vulnerable areas of timber frame walls are located in the interfaces between their different original sub-components (framework to infill, framework or infill to outer surface) and between these and new materials, including the prosthesis. Assuming that hygrothermal conditions of the environment are settled in compliance with the current standards parameters, careful attention should be paid to unintended consequences of interventions which can modify the original properties and performance, e.g. by reducing the porosity of the surface wall or increasing its stiffness.

Starting from the timber skeleton, original warped members should not be straightened, in compliance with the conservation principles (i, *section 5.3.1*), while all replaced wood should be properly seasoned and treated to lower moisture levels, provided with physical and/or chemical barriers, and have wood preservatives applied.[103]The dismantling and reassembling of the wooden components is relatively easy; however, different stress conditions can occur when severely decayed lumbers require replacement. All interventions should allow evaporation of the internal moisture. The interactions between timber framework and infill with plaster are crucial for the maintenance of the original properties of the wall. The contact between the masonry and infill can result in interstitial condensation and greater susceptibility to biological attacks, as understood since ancient times.[104] However, lime mortar is a counter-acidifying factor: the water in the mortar provides basicity to the timber skeleton, by reversing the pH in wood, and thus discouraging the proliferation of insects or other species of fungi that feed on wood within an acidic environment.

The reliability of repair (or strengthening) of the timber skeleton or the joints can be hampered by the placement of inelastic infill that interferes with the shear transfer mechanism. Infill plays an important role in stiffening the joints of the wall, preventing early brittle failure. The conventional current practice encompasses a variety of solutions (from *I1* to *I2*, *Table 5.03*), with different impacts on the ductility and energy dissipation. The new infill should also act as buffer zone for absorbing possible cracks during its entire life cycle and under seismic loading. For each solution listed in *Table 5.03* strengths and weaknesses can be encountered. For example, the use of mineral wool or sandwich panels is a cost-effective solution for meeting acoustic, thermal, and fire insulation standards in the current legislation; on the other hand, these panels differ completely from the original infill in terms of resistance capacities and chemical-mechanical characteristics.

With regard to the carpentry joints, it is noteworthy that each original carving reduces the effective (residual) cross-section of its wooden component by itself, a condition worsened by biological attacks or severe alteration of stress conditions (or eccentricity of loading).[105] Repair of the original carpentry joints, by replacing the original decayed section or substituting the original (or missing) fasteners, requires a certain level of technical skill which is being lost. Metallic connections (e.g. stainless steel bolted plates, pins, self-tapping screws) or epoxy resin adhesives show some drawbacks compared to wooden carpentry joints (pegs, pins, notched joints), the most important of which are respectively the moisture condensation in the interface between timber and steel components and the low reversibility of resin adhesives.[106] A peg or pin, especially if made of a hardwood species, offers satisfactory strength and can be even more effective than a nail. The aesthetic impact – another drawback of the use

[103] *Appendix D.1* (viii)
[104] e.g. art. 11, *Istruzioni* (1984). See *Chapter 3*, *section 3.3.1*
[105] (Cruz, et al. 2015)
[106] (Ceraldi, C.; D'Ambra, C.; Lippiello, M.; Prota, A. 2017)

of metallic connectors – can be overlooked when the structure is covered by surface finish. On the other hand, the many advantages of steel connections compared to wooden pegs/pins are increased strength, more practical feasibility, and a greater legislative body, as well as greater availability in the market.

Steel reinforcements have been employed since the 19th century, so their durability and effectiveness have been largely tested. Being internal timber frame walls, the climatic conditions are not as adverse as is the case for external walls, therefore some drawbacks can be omitted in these specific case studies (e.g. the condensation on steel fasteners that causes an accumulation of humidity and thus decay of the wood). As regards resin repair, more in-depth discussion is required. Since epoxy resins are synthetic chemicals, whose durability remains a crucial question (their use dates back only a few decades),[107] they should be used only when carpentry repairs are not feasible. The epoxy resins can be used for grouting and filling of timber sections damaged by fungal and insect attack, but their use is not recommended in the carpentry joints because they prevent free movement under stress. Additionally, the replaced parts in resin materials behave in mechanically different ways by inducing damage at the interface between the two different materials, as shown in literature by Swedish experts.[108] Due to the need for sealing this type of permeable wall, the TFW as an internal wall (or external wall) [109] was always plastered. Therefore, the placement of finish is highly recommended to protect the rough surface, especially because softwood – which is the most common employed in such walls – is more prone to fast decay. Careful attention should be taken in the selection and application of the plaster; depending on its composition, different degrees of adhesion and pathology can result in defective strength and permeability. Considerations similar to those for the infill of TFW apply to its surface finish, as well as other requirements (e.g. washability). The heterogeneity of the wall structure (*F* and *I*) may reduce the durability and cohesion of the coating when a mono- or multi-layer plaster or a cement-based mortar with acrylic additives is placed on the wall. Lime-based plasters and hydraulic lime coatings are preferable for their breathable qualities, i.e. the ability of materials to absorb and release moisture as vapour (hygroscopicity) or as liquid (capillarity). As verified by a number of years in the current practice, cement-based materials can produce crumbling in plaster and prevent the breathability of the surface by engendering thermal conflict. When an original ceramic surface has to be replaced – generally in areas such as kitchens, bathrooms, and in many cases as a skirting – it should be taken into account that the traditional solution of the first layer (*massas de emboço*) employed lime that had been made by exposing virgin lime to air or water (*cal extinta*) and included animal tallow.[110] As an alternative to all types of plaster, the designer can opt for plasterboard, whose positive features are economic and practical feasibility, indoor comfort and energy efficiency, the opportunity to hide piping (or other equipment). However, although it does not cause harmful chemical reactions, plasterboard can also imply a high visual difference compared to the original wall due to the increase in thickness, as well as tactile difference.

[107] Patented in the 1930s, these were applied for repairing timber in 1960s and 1970s. An extensive overview of resin repairs for historic structural timber is provided by Cleary (Cleary, R. 2014).
[108] (Larsen, K.E.; Marstein, N. 2006, 37)
[109] External timber frame walls of *Pré-pombalino* dwellings in Lisbon were plastered against weather and fire hazard (*Chapter 2*, *section 2.3.1*).
[110] Santos specifies the importance to avoid gypsum, which causes the crumbling of the support and the ceramic tiles (Mascarenhas, J.M. (ed.) 2005, 129). The traditional layers of the timber frame walls are described by Santos, based on Oliveira's building manual (18th century) and on-site analysis (Oliveira, E.F. 1882-1911) (Santos, V.L. 1994, II.4.1.54-56).

5.4 Multi-criteria analysis of rehabilitation techniques for traditional timber frame walls

The selection of the best set of interventions for the rehabilitation of *Pombalino* buildings is essential for their maintenance over the centuries. This research narrows the scope of application by focusing on the development of an informed methodology for ranking the rehabilitation techniques for traditional timber walls, whose seismic resistance has been fully documented based on empirical evidence and experimental tests.[111]

5.4.1 Outlook of Macbeth analysis and importance of expert judgments

When a variety of non-numerable and non-homogeneous criteria have to be taken into account for the selection of the best solution among several options, the decision-making process can be supported by Multi-criteria Decision Analysis (MCDA).

Although MCDA models can guarantee transparent and interactive procedures, these methods are rarely applied for questions regarding the preservation of historic structures, e.g. for the evaluation of cultural assets regarding solutions for their reuse[112] or for the assessment of different rehabilitation techniques.

Depending on the time perspective of its impact, the decision problem can be strategic, tactical, or operational.[113]This analysis is short term and its type of structure is well-defined, so it can be classified as operational (*Table 5.05*).

Table 5.05 – Categories of decision problems, adapted from (Ishizaka, A.; Nemery, P. 2013)

Decision	Time perspective	Novelty	Type of structure	Automation
Strategic	long term	new	low structured	low
Tactical	medium term	adaptive	semi-structured	middle
Operational	**short term**	**every day**	**well-defined**	**high**

Due to the large number and great diversity of MCDA methods,[114] it is difficult to justify the choice of a specific method for addressing a demanding decision problem. Arrow alleges that none of the existing MCDA methods can be considered faultless for all types of decision-making problems.[115] This scholar explains that the basis of MCDA methods is compliance with the axioms of universality, unanimity, and independence (though not always simultaneously).

To gain insight into MCDA software and understand what it is capable of improving, a comparative analysis was recently done within the IMPERIA project,[116] whose results are reprocessed in *Table 5.06*. This report Improving Environmental Assessment by Adopting Good Practices and Tools of Multi-criteria Decision Analysis aims to analyse the software and the resource collections classified under the term multiple attribute decision making and

[111] (Santos, S. P. 1998) (Poletti, E. 2013) (Gonçalves, A.M.; Gomes-Ferreira, J.; Guerreiro, L.; Branco, F. 2014)
[112] (Ferretti, V.; Bottero, M.; Mondini, G. 2014)
[113] (Ishizaka, A.; Nemery, P. 2013)
[114] In spite of this great variety, all models are generally structured as follows: (i) construction problem; (ii) criteria; (iii) alternatives; (iv) analysis of the results; and (v) sensitivity analysis.
[115] Up to now, Arrow's theory (Arrow, K.J. 1951) is supported by several scholars (Simpson, L. 1996) (Guitouni, A.; Martel, J.M. 1998) (Ishizaka, A.; Nemery, P. 2013). The great variety of MCDA procedures can be deemed as a strong and, at the same time, a weak point (Roy, B.; Bouyssou, D. 1993).
[116] (Mustajoki, J.; Marttunen, M.; FEI 2013)

thus by omitting the analysis of software for multiple objective decision making, sorting problems and portfolio analysis. The following six parameters are taken into account in the IMPERIA project for the evaluation of several MCDA models: (i) process support; (ii) model construction; (iii) criteria weighting; (iv) analysis of results; (v) group decision support; (vi) other information (i.e. description and characteristics of the software, application areas, useful or innovative features from EIA/MCDA viewpoint); and additional information.

Table 5.06 – M-Macbeth performance and the other MCDA tools from (Mustajoki, J.; Marttunen, M.; FEI 2013, 18-26)

Criteria evaluation	Descriptors	Scale evaluation	M-Macbeth scale	other MCDA software (total 24)	Comments on M-Macbeth performance in relation to other MCDA tools
1. Process support	general purpose software	Y or N	Y	Y=19; N=4; - =1	Some expertise is typically required. Biases e.g. in the weight elicitation may arise from an improper use of the method. Some decision analysis modules have implemented on-line guidance (*PUrE2*, *PlanEval)*. Some improvement (e.g. tab-paneled interface) should be introduced into M-Macbeth.
	process support		N	Y=9; N=15	
	hand-in-hand guidance		N	Y= 4; N=20	
	level of expertise required	1L, 2L, 3L	3L	3L=17; 2L=4; 1L=2; - =1	
2. Model construction	hierarchical model	Y or N	Y	Y=18; N=4; - =2	The model construction of all software is quite similar, based on hierarchical organization of the criteria, a matrix-like consequence table for inputting the criteria-wise data of the alternatives into the model. M-Macbeth is user-friendly because it allows easy managment of data input phase.
	consequences table		Y	Y=19; N=3; - = 2	
	visual scoring		Y	Y=18; N=4; - = 2	
3. Criteria weighting	visual weighting	Y or N	Y	Y=18; N=4; - = 2	Almost half of the software provides support for both AHP and MAVT/MAUT. M-Macbeth is one of the few that provide support for both outranking and MAVT/MAUT methodologies. Unlike M-Macbeth, some software provide explicit support for modelling uncertainty/imprecision (i.e. *Analytica*, *DecideIT*, *GMAA*).
	AHP/Pairwise comparison		Y	Y=11; N=11; - = 2	
	MAUT/MAVT		Y	Y=18; N=4; - = 2	
	swing		N	Y= 11; N=11; - =2	
	outranking		Y	Y=3; N=20; - = 1	
	modelling of uncertainty/imprecision		N	Y=8; N=14; - = 2	
	decision trees		N	Y=3; N=19; - = 2	
4. Analysis of the results	visual graphs	Y or N	Y	Y=21; N=1; - =2	Similarly to the majority of the software, M-Macbeth provides visual graphs of results, such as thermometer and x-y graphs. In addition to the traditional one-way sensitivity analysis, M-Macbeth could be improved by including statistical approaches or by improving the x-graphs (by adding a third dimension with the size of the ball indicating the alternative).
	overall values		Y	Y=19; N=3; - =2	
	sensitivity analysis		Y	Y=19; N=3; - =2	
	x-y graphs		Y	Y=16; N=6; - =2	
	written report		N	Y=8; N=14; - =2	
5. Group decision support	group model	Y or N	N	Y=6; N=16; - =2	The majority of MCDA software supports the group facilitation in no explicit way or not at all, with the exception of few tools (e.g. *1000Minds*, *D-Sight*, *MakeItRational, Web-HIPRE*, *PlanEval*).
	excel model		N	N=15; Y=7; - =2	
6. Other information I	application areas	descriptive	generic	various (e.g. general, generic, forest management or planning, renewable energy resources, indoor air quality)	The majority of MCDA software (including M-Macbeth) are general-purpose. Some specific tools are tailored for forest planning (*Craft*, *MESTA*), for air quality modelling (*PUrE2*), and renewable energy resources.
	useful or innovative features from the EIA/MCDA viewpoint		various graphs	various (e.g. tab-based web interface, brainstorming SMAA-like analysis of weights)	As regards process support, tab-panels should be applied in all software since they provide an indication of the phases of the process and guidelines for carrying out the process, as well as for going back and forth between the phases. Macbeth's two-or-more dimensional graphs are useful.
7. Other information II	people/organisations behind the software	-	Bana e Costa, De Corte, Vansnick	-	Approximately half of the software was developed by academics and the others by commercial actors. The developers of academic software typically provide the software for free, but with a restriction to academic or non-profit purposes. M-Macbeth was devolped commercially and is availble; its free demo version limits the number of evaluation criteria to four.
	price	€, £,$	Free demo/ academic or professional licence	depends on the licence (from open source to £2000)	

Among several MCDA models devised to support the decision-making process, the Macbeth method, which stands for *Measuring Attractiveness by a Categorical Based Evaluation Technique*, was chosen for its efficacy, which has been demonstrated in different contexts, e.g. environmental planning, urban strategies, and eco-system

management.[117] This problem-solving model is commonly used in literature by itself or coupled with other models like Data Envelopment Analysis (DEA) and Utilitèt Additives (UTA) (*Appendix D.3*).[118] First put forward in the early '90s in Bana e Costa's doctoral thesis[119] with the collaboration of Vansnick, this method was later updated with further collaboration by De Corte. Numerous practical applications of this method show its great potential for supporting decision-makers. The most interesting involves the public strategic decision-making processes in a context of limited resources.[120]

In keeping with all MCDA methods, Macbeth overcomes the limitations of every mono-criteria models by including multiple and non-homogeneous attributes (qualitative and quantitative). Macbeth was chosen by the author for its ability to incorporate a large number of preferences (or amount of subjective information) built through pairwise comparison judgments. It can thus be tailored in order to match the specific requirements of the analysts, through a co-participative decision-making process. It also resolves contradictions between interests of single actors or with inconsistent scores by providing a complete ranking based on an additive aggregation approach. Macbeth uses an interval scale, whereas the *analytic hierarchy process* (AHP), also a full aggregation method, uses a ratio scale.[121] Constructing such scales calls for interacting with multiple decision-makers. Their preferences represent the average or typical opinion of the whole group.[122] Macbeth outputs consist of a ranking of the combinations[123] and the setting up of sensitivity and robustness analyses; the effort involved in constructing the model is compensated by the richness of the outputs.[124] Macbeth is also user-friendly for its intuitive graphical interface and the fast processing results. It can bypass inconsistent judgments in the pairwise comparison matrix and suggests solutions. It is also an interactive tool, due to the possibility to analyse the sensitivity of every output based on the variations of judgements, performances, and scores or weights.[125] Additionally, the thermometer can be easily modified by varying the data input: i.e. the user can adjust bars by dragging them with mouse, similarly as on the data input phase.

However, Macbeth is time-consuming as it requires more questions than other elicitation techniques (e.g. the swing weighting)[126], especially when dealing with a high number of alternatives and criteria sets, as in this research analysis. Many other MCDA models are more accessible than M-Macbeth software because some are compatible with Microsoft Office and have MS-Excel-like interfaces to input the data, (e.g. *Promax* and *Pure2*)[127] and have MS Excel-like interfaces to input/export the data, and can provide written reports (e.g. *1000Minds*, *Decision Tools*, *Hiview 3*, *Logical Decisions*, *MakeItRational*, *PlanEval*) (*Table 5.06*, 4th criterion).

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[117](Bana e Costa, C.A. 1988) (Bana e Costa, C. A.; Oliveira, R.C. 2002)
[118] (Rangel, L.A.; Mello, J.C.; Gomes, E.G.; Gomes, L.F. 2003)
[119] (Bana e Costa, C.A. 1992)
[120]Among many case studies, we mention just a few: (Lourenço, J.C.; Morton, A.; Bana e Costa, C.A. 2012) (Hummel, J.M.; Oliveira, M.D.; Bana e Costa, C. A.; IJzerman, M.J. 2017).
[121] (Velasquez, M.; Hester, P.T. 2013, 58-59)
[122] (Mustajoki, J.; Marttunen, M.; FEI 2013, 5)
[123] The complete ranking of the options is defined as a global score. It is a full aggregation approach (or *American school*), i.e. a low score on one criterion can be compensated by a good score on other criterion (*section 5.4.3*). The outranking approach (or *French school*), based on pairwise-comparisons can solve these incompatibilities (Ishizaka, A.; Nemery, P. 2013).
[124](Ishizaka, A.; Nemery, P. 2013)
[125] (Bana e Costa, C.A.; De Corte, J.M.; Vansnick, J.C. 2015, 75)
[126] Swing weighting is a numerical elicitation technique, while Macbeth is non-numerical.
[127] These multi-criteria methods have Office 2010 like interfaces with a ribbon (Mustajoki, J.; Marttunen, M.; FEI 2013, 10).

5.4.2 Problem structuring: evaluation criteria and scenario models

Once a preliminary analysis of the problem context was identified (*section 5.2*), Macbeth analysis was structured into distinct stages:

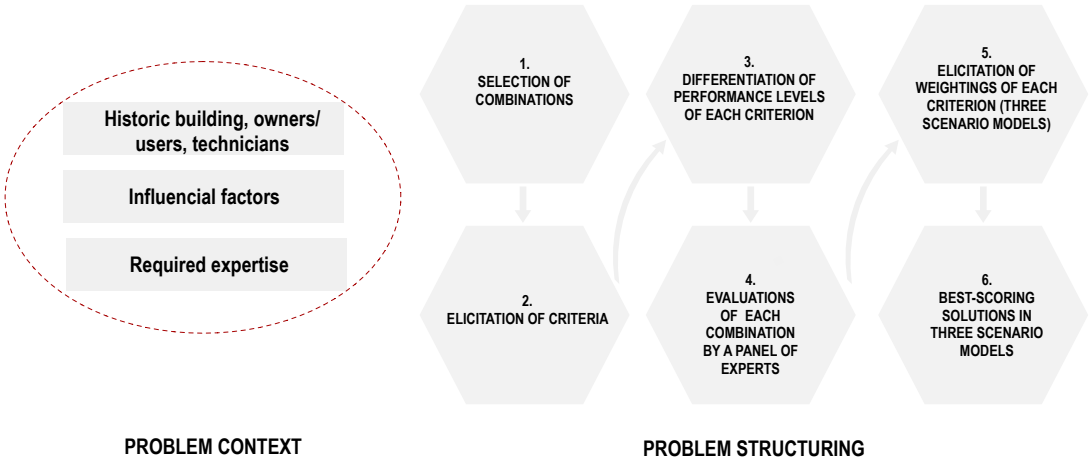

Figure 5.10 – Workflow

After the elicitation of 131 rehabilitation techniques (*section 5.3.4*), their evaluation process was carried out in three steps:

1. elicitation of evaluation criteria with respective criteria descriptors and performance levels (2nd phase, *Figure 5.10*);
2. evaluation of 131 rehabilitation techniques in a 0-100-scale by the experts (4th phase, *Figure 5.10*);
3. definition of three scenario models (6th phase, *Figure 5.10*).

A set of five criteria stemming from the leading principles discussed in *section 5.3.1*, are selected so that each one satisfies Roy's axioms: exhaustibility, cohesion, and non-redundancy[128](*Table 5.07*):

- *Material compatibility* (MC);

This parameter depends on physical-mechanical and chemical matching of the new (or reused) components to the original ones. MC is related to the intervention impact on the historical buildings in terms of durability and effectiveness.

- *Material permanence* (MP);

This criterion regards the permanence of the original materials after the interventions on the historical building. All interventions entail the removal of the surface finish, after a detailed documentation of the interventions in all their phases.

- *Structural reliability* (SR);

This parameter is evaluated by comparing the mechanical behaviour (e.g. strength, ductility, and energy dissipation) before and after the interventions on the historical building.

[128] (Roy, B. 1996)

- *Structural authenticity* (SA);

It is based on the level of modification of the original structural system (either geometrical or structural configuration of the timber wall), which influences the structural performance in terms of stiffness, mass distribution, and loading level.

- *Visual-tactile appearance* (VTA).

It regards the aesthetic compatibility of the intervention on wall surface appearance. The aesthetic compatibility typically belongs to the material compatibility (MC), however, it was considered only in this criterion in order to avoid redundant evaluations. The tactile difference between the original component and the replaced one is also taken into account in this criterion.

Table 5.07 – Multi-criteria performance descriptors

Criterion	Sub-criterion		Performance Descriptors
Material Compatibility (MC)	**physical compatibility**		porosity and pore size distribution, variation of the moisture transport properties, such as absorption and drying rate, thermal, and hygric expansion
	chemical compatibility		chemical composition and reactions, solubility
	mechanical compatibility		hardness, cohesion, and deformation
Material Permanence (MP)	**degree of intrusiviness**		permanence of original components after the intervention
Structural Reliability (SR)	**strength**		horizontal and vertical load capacity
	ductility and energy dissipation		lateral deformation capacity; ability to deform and mechanically degrade without collapse
Structural Authenticity (SA)	**consistency with the:**	**original structural layout**	mass distribution, stiffness, and load concentration
		structural wall typology and joint type	dissipation capacity of walls and joints
Visual -Tactile Appearance (VTA)	**visual appearance**		visual permanence of the original features before and after the intervention (thickness, colour, gloss)
	tactile appearance		tactile permanence of the features before and after the intervention (roughness)

Once the qualitative performance descriptors of each criterion were established (*Table 5.07*), the experts determined the respective performance evaluation levels, whose interval values are defined through the Macbeth pairwise questioning procedure. Four performance evaluation levels were defined for MP, SR, SA, and VTA (high, moderate, low, and very low), and three evaluation levels for MC (high, moderate, and very low). For MC criterion and for MP (one sub-component of TFW, timber framework), the level performance *very low* corresponds to "0", whereas in the other criteria there is an additional level performance, which is "0", as shown in *Table 5.07*.

The panel of technical experts on historic timber frame buildings was composed of two representatives for each field: chemistry, timber engineering and architecture. The elicitation of the best-scoring solutions was influenced by their respective disciplinary sphere. Chemists evaluated the alternative options under MC criterion, architects (experts of architectural heritage preservation) under MP and VTA criteria, and timber engineers under SR and SA criteria.

In order to obtain numerical values, it was necessary to more clearly define the distances involved between the various evaluation levels. These would vary for judgments about different sub-components. The experts defined the difference of attractiveness between two levels of performance by selecting the most suitable adjective among seven semantic categories included in the Macbeth method (no, very week, week, moderate, strong, very strong, or extreme). It was therefore possible to determine under the Material Compatibility criterion, for example, that the difference in attractiveness between *High* and *Moderate* evaluations was *very strong* in reference to Framework Infill and Joints, while when considering Surface Finish the difference between *High* and *Moderate* was seen as *weak*. These qualitative expert judgments were translated into cardinal values by M-Macbeth (*Figures 5.11*, *5.12*).

Table 5.08 – Performance levels for each criterion based on experts' judgments

Criterion	Performance Levels	
Material Compatibility (MC)	**High (H)**	Properties are similar physically (e.g. very similar porosity and pore size distribution, very low variation of the moisture transport as absorption and drying rate, no thermal and hygric expansion), chemically (e.g. similar chemical composition, no harmful chemical reaction, similar solubility) mechanically (e.g. hardness, cohesion and deformability similar to the original material). Additionally, the treatment will have a long-term durability.
	Moderate (M)	Slightly or moderately different physical-mechanical features (e.g. moderate variation of the porosity and pore size distribution,moderate variation of the hardness/cohesion, moderate variation of drying and hygroscopic behavour, different chemical features, no harmful chemical reaction or byproducts).
	Very Low (VL)	Different from the original properties (e.g. chemical composition and solubility, formation of byproducts, remarkable difference in hardness and deformability, very different drying behaviour).
Material Permanence (MP)	**High (H)**	Negligible replacement of original components.
	Moderate (M)	Limited replacement of original components.
	Low (L)	Significant replacement of original components.
	Very Low (VL)	Complete replacement of original components.
Structural Reliability (SR)	**High (H)**	Significant improvement of mechanical behaviour (strength, ductility, and energy dissipation).
	Moderate (M)	Moderate improvement of mechanical behaviour (strength, ductility, and energy dissipation).
	Low (L)	Low improvement of mechanical behavior (resistance, ductility, and energy dissipation).
	Very Low (VL)	Non significant improvement or even worsening of the mechanical behaviour (resistance, ductility, and energy dissipation).
Structural Authenticity (SA)	**High (H)**	The original geometry and structural configuration are mantained.
	Moderate (M)	About the same geometry and structural configuration as the original ones.
	Low (L)	Different from the original geometry and structural configuration.
	Very Low (VL)	Very different from the original geometry and structural configuration.
Visual-Tactile Appearance (VTA)	**High (H)**	Visual, tactile, and spatial features are similar to the original.
	Moderate (M)	Spatial features are similar to the original, wheras the tactile consistency is different.
	Low (L)	Increase of thickness, differences in tactile and material consistency.
	Very Low (VL)	Relevant differences in thickness and in tactile, material, and colour consistency.

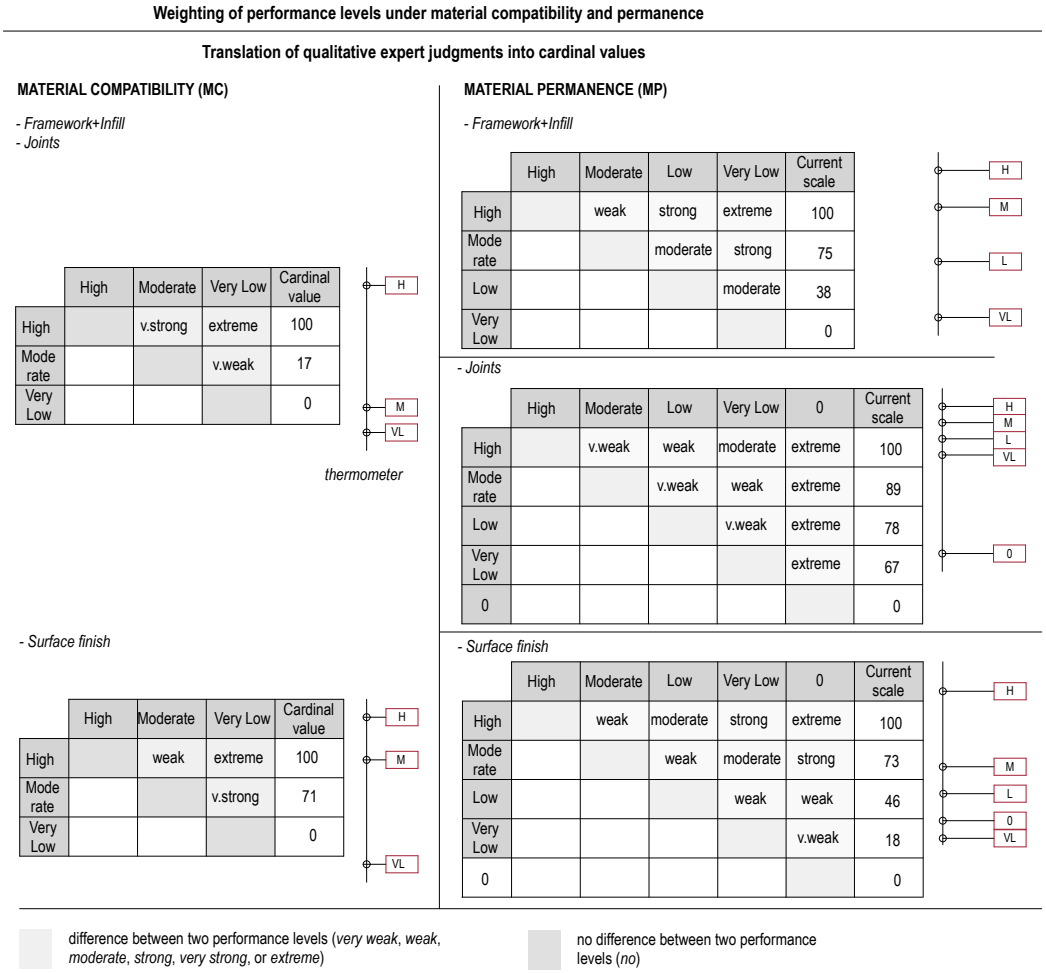

Figure 5.11 – Macbeth judgment matrices related to the difference of attractiveness between the performance levels of MC and MP, with the respective thermometers

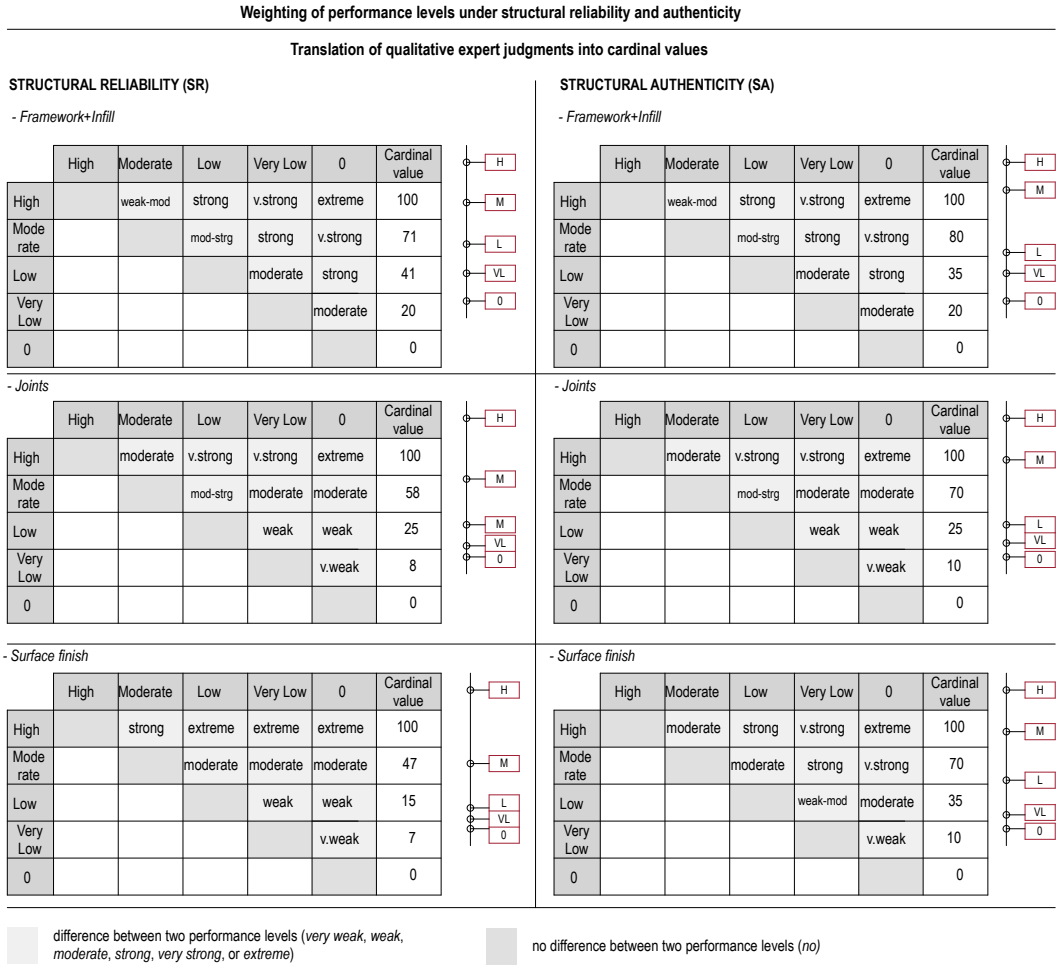

Figure 5.12 – Macbeth judgment matrices related to the difference of attractiveness between the performance levels of SR and SA, with the respective thermometers

The difference of attractiveness between the sub-components of TFW (weights) is determined through the same pairwise procedure for all criteria except for the visual-tactile appearance (VTA). In fact, VTA is related only to the surface finish, and thus the evaluations are performed directly for the whole wall (*Figure 5.13*).

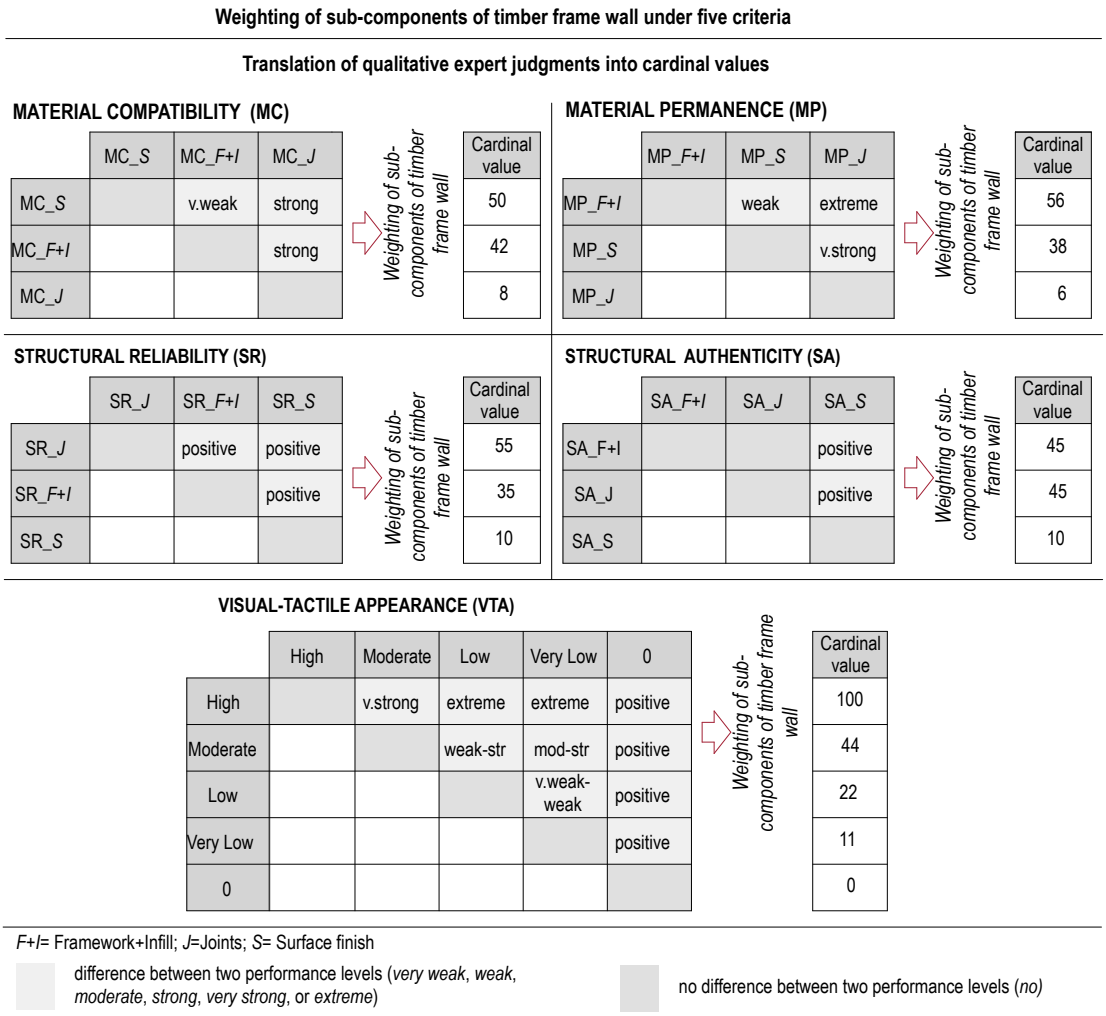

Figure 5.13 – Macbeth judgment matrices related to the difference of attractiveness between each sub-component of TFW in each criterion

Table 5.09 – Summary chart of cardinal values calculated from Macbeth matrices

Criterion	Sub-component of TFW	Weights	Evaluation level (EL)				
			H	M	L	VL	0
Material compatibility (MC)	F+I	0.42	100	17	-	0	-
	J	0.08	100	17	-	0	-
	S	0.50	71	17	-	0	-
Material permanence (MP)	F+I	0.56	100	75	38	0	-
	J	0.06	100	89	78	67	0
	S	0.38	100	73	46	18	0
Structural reliability (SR)	F+I	0.35	100	71	41	20	0
	J	0.55	100	58	25	8	0
	S	0.10	100	47	15	7	0
Structural authenticity (SA)	F+I	0.45	100	80	35	20	0
	J	0.45	100	70	25	10	0
	S	0.10	100	70	35	10	0
Visual-tactile appearance (VTA)	-	-	100	44	22	11	0

Additionally, the threshold between what constitutes *repair vs strengthening* by using the weighted assessment of the combinations in the SR criterion (*Table 5.09*). The threshold value between repair and strengthening measures ($t_{r\text{-}s}$) was determined by calculating the weighted average of the evaluation level defined as 'low' (E_{Lp}) of the SR criterion, as shown in equation 1:

$$t_{r-s} = \sum_i (ELp_i \cdot WF_i) \qquad (1)$$

where W_{Fi} is the weight of each sub-type of intervention (rehabilitation technique) used to determine each partial value score of the evaluation under SR criterion.

The result for $t_{r\text{-}s}$ can be rounded up to 30 (equation 2):

$$t_{r-s} = 41 \times 0.35 + 25 \times 0.55 + 15 \times 0.10 = 29.6 \qquad (2)$$

where 41, 25, and 15 are the value scores of the evaluation level 'low' attributed respectively to *F+I*, *J*, and *S*, whereas 0.35, 0.55, and 0.10 are the weights respectively attributed to *F+I*, *J*, and *S*.

The next step consisted of the assignment of a relative weight to each criterion. This step involved setting up separate Macbeth models corresponding to three design-related models. These are listed according to ascending order of intrusiveness of the intervention, depending in turn on the degree of authenticity and on the level of structural safety of the building (*Figures 5.12*, *5.13*).

Finally, each scenario, to which the value scores of the options are associated, can be selected by the decision-maker (building owners and/or users) on the basis of the state of conservation of the building components.

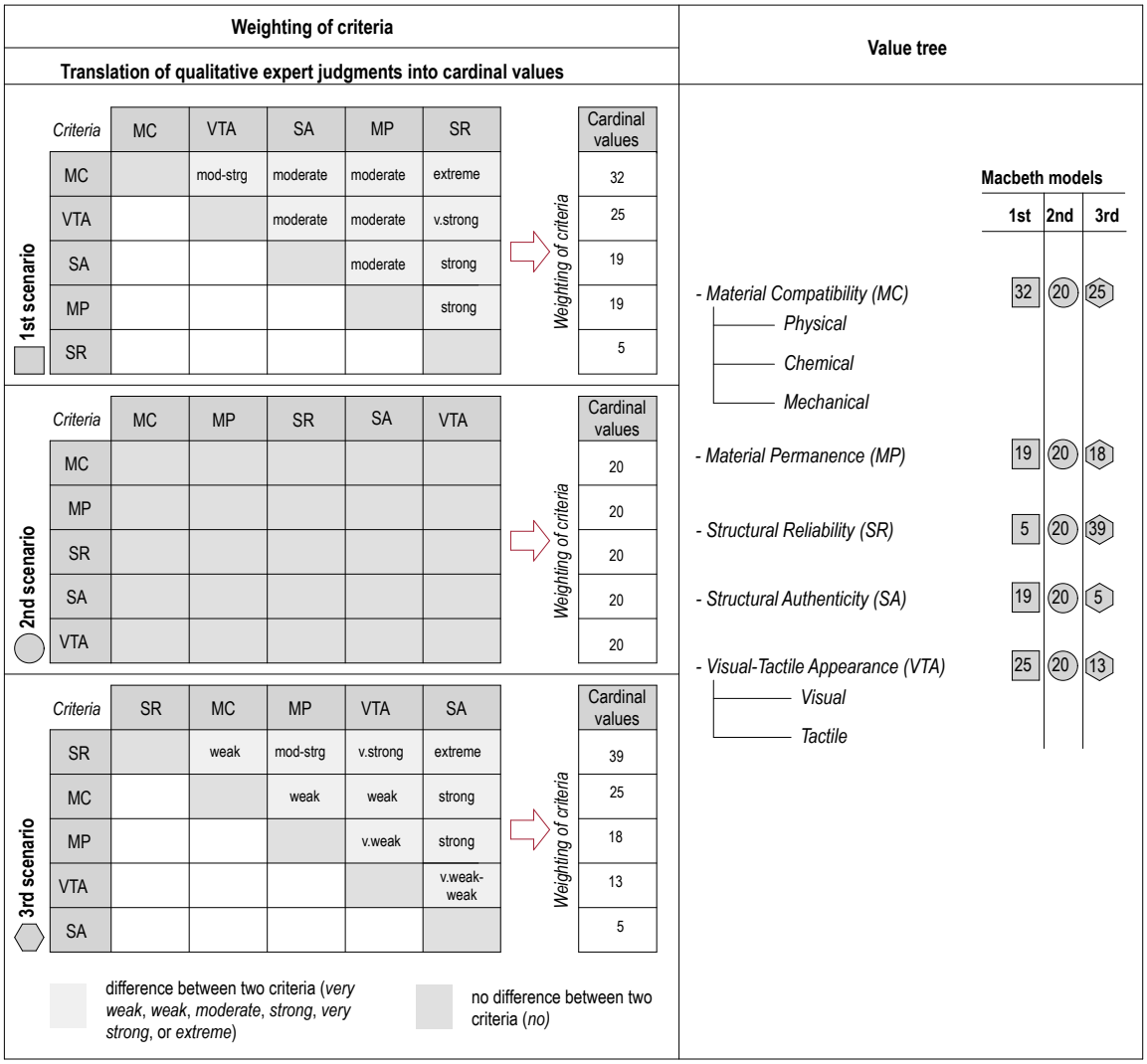

Figure 5.14 – Macbeth judgment matrices related to the difference of attractiveness between each criterion (three scenario models)

5.4.3 A set of incomparability and consistency in the pairwise evaluations

> "A series of controversial issues are implicit in the complex decision-making process of seismic retrofit, where both rational and counter-intuitive solutions can satisfy some of the most critical aspects of multi-level performance-based seismic retrofit criteria".
>
> (Pampanin, S. 2006, 120)

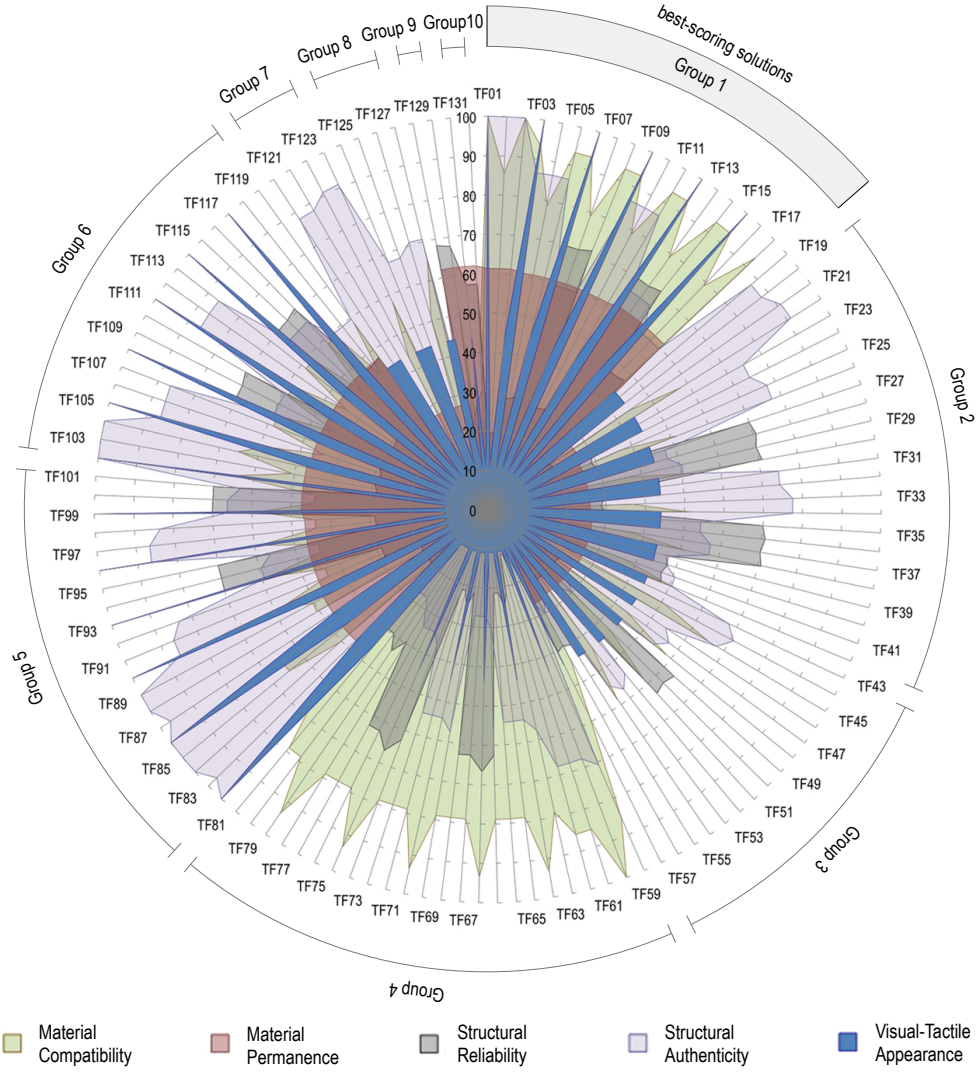

Figure 5.15 – Evaluation scores of 131 alternatives under five criteria (© S. Stellacci)

A set of incomparability,[129] arising from possible diverging judgments of the experts on the different criteria can be identified in *Figure 5.15*. These can be identified in relation to a pairwise comparison of the global scores of the material compatibility (MC) *versus* the structural reliability (SR). In fact, the individual criterion scores of these solutions reach the highest value for MC and low values for SR. This can be explained by the weightings attributed respectively by chemists and timber engineers to repair measures *J1a* (= *J1b*) in the calculation of the global

[129] (Ishizaka, A.; Nemery, P. 2013)

assessment for these criteria. When evaluating MC, the intervention on the joints is weighted by a very low value (0.08), whereas it is weighted by a high value (0.55) when referring to the structural reliability (*Table 5.09*).

Another group of incomparability arises in the case of replacement of the infill (*F1+I3*, *Table 5.04*): in the set of solutions between TF58 and TF81, MC ranges from 86 to 79, whereas VTA equals 11, as shown in *Table 5.10*.

On the other hand, the evaluations of MC and of SA show consistent outputs (*Figure 5.16*, *Table 5.10*). The best-scoring solutions for MC also score the best for SA (e.g. *TF01-TF03*). However, this consistency is not found when the surface finish is made of cement mortar (*S1b*), or of cement-based mortar with metal mesh and acrylic render (*S2*). In these cases, the solutions achieve moderate values for SA, due to the low weighting (0.10) applied to the surface finish under SA. Conversely, the low scores for MC result from the high weighting attributed to surface finish (0.50).

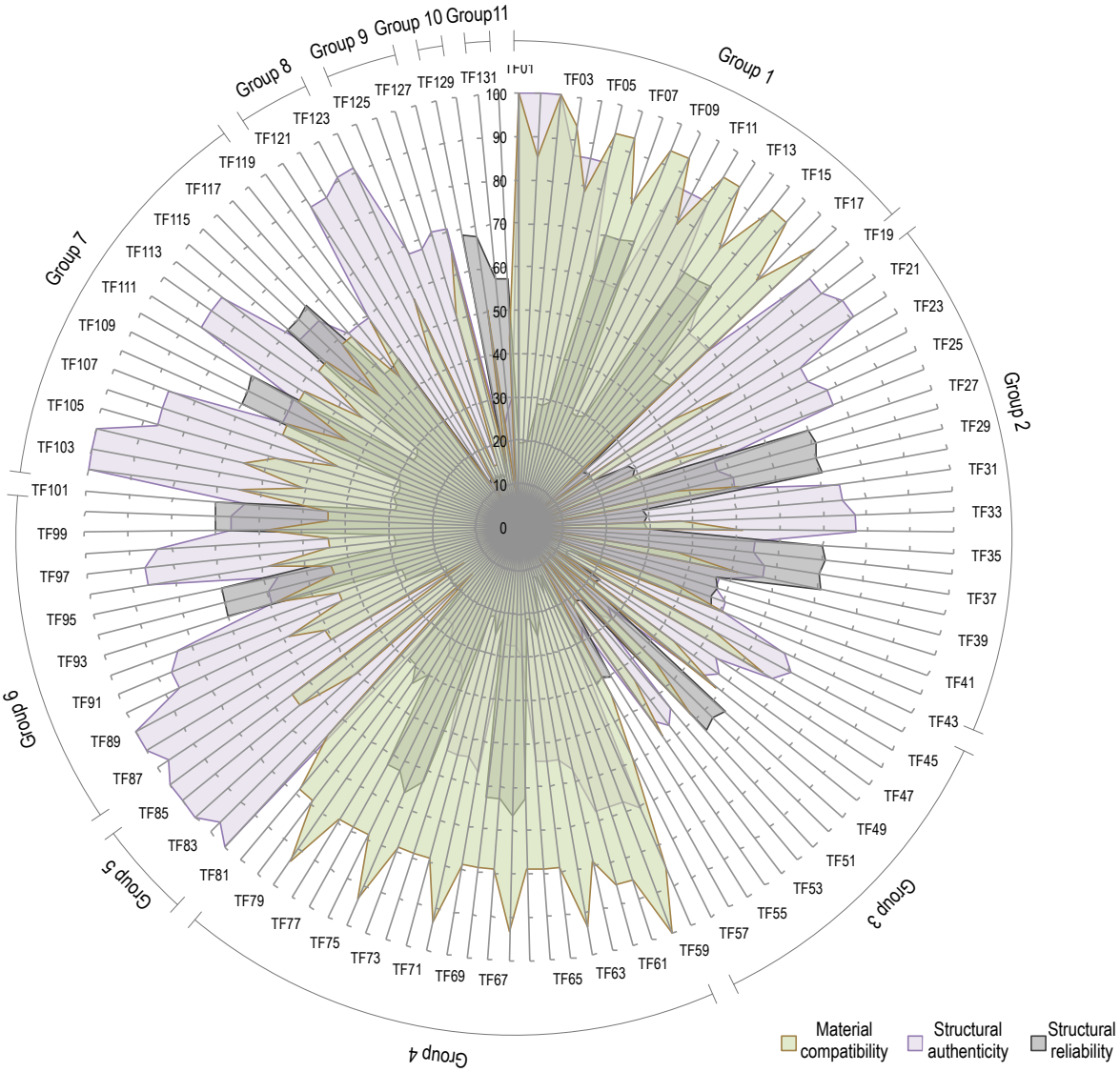

Figure 5.16 – Evaluation scores under MC, SR, SA criteria (© S. Stellacci)

Table 5.10 – A set of incomparability and consistency in the pairwise evaluations (left: MC *vs* SR, MC *vs* SA; right: MC *vs* VTA)

Identification	Evaluations		
	SR	MC	SA
TF01	19	100	100
TF02		86	
TF03	20	100	
TF04	29	93	87
TF06	30		
TF10	29		
TF12	30		
TF59	16	100	70
TF63	25	93	
	INCOMPARABILITIES		
		CONSISTENCIES	

Identification	Evaluations	
	MC	VTA
TF02, TF58, TF60 TF61	86	11
TF05, TF08, TF11, TF14, TF17, TF19, TF62, TF64/TF66, TF68/TF70, TF72/TF74, TF76/TF78, TF80, TF81	79	11
	INCOMPARABILITIES	

The spikes in *Figure 5.15* reflect the large differences of the evaluations of consecutively-listed interventions in *Table 5.04*. The evaluations under MC and VTA constitute a less uniform area in comparison to the evaluation under SR (*Figure 5.16*).

The shape of the radar graphs varies depending on the criteria for several reasons. Firstly, this difference depends on how the list of each group was ordered: each group of combinations was listed by varying the type of joints and surface finish according to the type of the structure wall.[130] Because each group has the same intervention on the structure wall (*F+I*) and are listed according to the different interventions on the joints (*J*), the graph regarding SR presents less frequent peaks. Accordingly, the evaluations influenced by these two interventions (W_{if}: 0.35 for *F+I* and W_{if}: 0.55 for *J*) are more uniform. Conversely, there are different types of surface finish in the same group (e.g. lime-based mortar *vs* cement-based mortar with metal mesh and acrylic additives). Surface finish is a relevant component in the evaluations under MC (W_{if}: 0.50), therefor the evaluations under MC and the graph are less uniform[131]. In addition, there are only three possible evaluation levels (high, moderate, very low) for MC, whereas for the other criteria there are four (high, moderate, low, very low). As a result, the difference between consecutive performance levels for MC is higher than in the other criteria (see thermometer in *Figures 5.11*, *5.12*).

We can clarify this point by analysing two combinations of interventions that involve the same measures on timber framework and infill, and different interventions on the joint and surface finish:

TF59=(F1+I3)+(J1a *or* J1b)+(S3b) versus TF62=(F1+I3)+(J2a)+(S3a);

where *F1*: Removal of local decayed timber elements and replacement with autoclaved timber components; *I3*: No infill; *J1a* (or *J1b*): Recovery of carpentry joints by wooden pegs and pins *or* stainless steel nails; *J2a*: Strengthening carpentry joints by using stainless steel bolts; *S3b*: Placement of strips of wood with lime-based mortar; *S3a*: Placement of plasterboard.

[130] *section 5.3.4*

[131] The same applies to the radar graph in light blue related to VTA, where frequent peaks reflect the judgments of the experts.

The green peak in *Figure 5.15* is consistent with the expert preference under MC for TF59 and TF62. Their final scores are respectively 100 and 79[132] (*Table 5.11*, last column).

Table 5.11 – Comparison of evaluations of TF59 and TF62 under material compatibility (MC)

Sub-intervention	Evaluation under MC	Wif	Sub-intervention	Evaluation under MC	Wif	Sub-intervention	evaluation under MC	Wif	Intervention	Weighted score under MC
F1+I3	High compatibility (100)	0.42	J1a (or J1b)	High compatibility (100)	0.08	S3b	High compatibility (100)	0.50	**TF59**	**100**
F1+I3			J2a	Moderate compatibiity (71)		S3a	Moderate compatibity (71)		**TF62**	**79**

As regards MC, the importance of intervention (weightings) on the surface finish, as well as on framework and the infill, is higher than the intervention on the joint. The placement of lime-based mortar above the strips of wood is better than the placement of plasterboard, and wooden pegs (or stainless nails) are preferred to stainless bolts.

[132] Conversely, due to the lack of infill, TF59 and TF62 score very low for SA and VTA criteria (*Figure 5.15*).

5.4.5 Results and discussion

Based on the different target reliability levels – repair *vs* strengthening – distinct solutions are evaluated by the panel of experts as a function of their specific applicability to each scenario (*Figure 5.17*, *Table 5.12*):

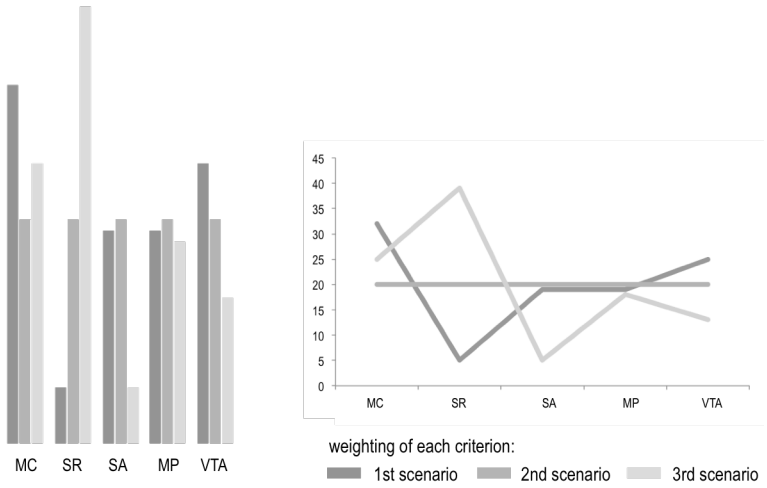

Figure 5.17 – Criteria weights of three-selected scenario models

- *1st scenario*:

  Pre-existing building conditions: high degree of integrity and authenticity; satisfactory level of structural safety.

  Expected results of intervention: The intervention aims at safeguarding the configuration of the components in service. Material compatibility is of great importance, so long as there remains good residual seismic behaviour of the building.

  The first scenario consists of repair measures whose structural reliability values are lower than 30;

- *2nd scenario*:

  Pre-existing building conditions: medium state of integrity; medium quality of structural and architectural features; satisfactory level of structural safety.

  Expected results of intervention: The intervention aims at the preservation of the original layout and the fulfillment of basic structural safety requirements.

  The second scenario consists of a combination of repair and strengthening measures;

- *3rd scenario*:

  Pre-existing building conditions: heavy alterations on the whole construction; low degree of structural integrity; medium/low quality of architectural features; unsatisfactory level of structural safety.

  Expected results of intervention: The intervention aims at improving the seismic performance of the building, thus the SR is the most important criterion followed by the MC.

  The third scenario consists of strengthening measures whose structural reliability values are higher than 30.

Table 5.12 – Criteria weightings in three selected scenarios and pre-existing conditions of the building

Pre-existing conditions		Scenario-design model	Criteria weightings (%)				
Degree of integrity and authenticty	Level of structural safety		MC	SR	SA	MP	VTA
High	Satisfactory	1st	32	5	19	19	25
Medium	Satisfactory	2nd	20	20	20	20	20
Low/Very Low	Unsatisfactory	3rd	25	39	5	18	13

There is another potential scenario that includes high degrees of integrity/authenticity (that should imply the analysis of repair techniques) of the building, and the unsatisfactory levels of structural safety (that should imply the analysis of strengthening solutions). This scenario is not analysed in this research, because these two parameters are strictly intertwined in this type of buildings. In fact, in *Pombalino* constructions a low degree of authenticity is consistent with a low level of structural safety and vice-versa. Conversely, in other problem context related to other types of buildings, less susceptible to seismic damage, this latter scenario should be included.

In order to provide a preliminary screening of these results, all the combinations characterized by a low global weighted score for all three scenarios (lower than 50) were discarded (*Table 5.13*). It means that 74 options, whose evaluations on each criterion are displayed in *Figure 5.18*, are thus excluded from the following analysis.

Table 5.13 – Discarded solutions: partial and weighted evaluations under five criteria

	Partial Evaluations					Weighted Eval.		
Short	MC	MP	SR	SA	VTA	1st	2nd	3rd
Group 2								
TF19	8	27	19	88	44	36	37	
TF20	8	27	20	88	44	37	38	
TF21	44	27	19	91	11	40	39	
TF23	1	26	29	75	44	32	35	
TF24	1	26	30	75	44		35	26
TF25	37	26	29	78	11	36	41	
TF26	52	26	30	78	44	49	46	39
TF27	1	26	71	48	44	29	38	41
TF28	1	26	72	48	44	29	38	41
TF29	37	26	71	52	11	33	39	46
TF31	1	26	29	75	44	32	35	
TF32	1	26	30	75	44	32	35	
TF33	37	26	29	78	11	34	36	
TF34	52	26	30	78	44	49	46	
TF35	1	27	71	55	44		39	41
TF36	1	27	72	55	44		40	42
TF37	37	27	71	58	11		41	46
TF39	1	27	47	48	44		34	32
TF40	1	27	48	48	44		34	32
TF41	37	27	47	52	11		35	37
TF42	52	27	48	52	44		45	45

	Partial Evaluations					Weighted Eval.		
Short	MC	MP	SR	SA	VTA	1st	2nd	3rd
Group 4								
TF58	86	5	12	72	11	46	37	
TF60	86	5	12	69	11	45	37	
TF61	86	5	12	69	11	45	37	
TF62	79	5	21	58	11	41	35	
TF64	79	5	21	55	11	41	34	
TF65	79	5	21	55	11	41	34	
TF66	79	5	64	30	11		38	49
TF68	79	5	64	27	11		37	48
TF69	79	5	64	27	11		37	48
TF70	79	5	21	58	11	41	35	
TF72	79	5	21	55	11	41	34	
TF73	79	5	21	55	11	41	34	
TF74	79	5	64	37	11		39	49
TF76	79	5	64	34	11		39	49
TF77	79	5	64	34	11		39	49
TF78	79	5	40	30	11		33	39
TF79	93	5	44	27	11		36	44
TF80	79	5	40	27	11		33	39
TF81	79	5	40	27	44		39	44

	Partial Evaluations					Weighted Eval.		
Short	MC	MP	SR	SA	VTA	1st	2nd	3rd
Group 3								
TF43	15	27	13	69	44	35	34	
TF44	52	27	12	72	11	39	35	
TF46	9	26	22	55	44	30	31	
TF47	44	26	21	58	11	34	32	
TF48	60	26	22	55	44	47	41	
TF49	9	26	65	27	44		34	39
TF50	44	26	64	30	11		35	44
TF52	9	26	22	30	44	26	26	
TF53	44	26	21	58	11	34	32	
TF54	60	26	22	55	44	47	41	
TF55	9	27	40	27	44	26	30	
TF56	44	27	40	30	11	30	31	
TF57	60	27	40	27	44	42	40	

	Partial Evaluations					Weighted Eval.		
Short	MC	MP	SR	SA	VTA	1st	2nd	3rd
Group 5								
TF83	15	47	20	97	44	44	45	
TF84	52	47	19	100	11	48	46	
Group 6								
TF87	15	47	20	97	44	44	45	
TF88	52	47	19	100	11	48	46	
TF91	44	47	29	87	11	44	44	
TF92	44	47	29	84	11	43	43	
TF97	44	47	29	87	11	44	44	
TF98	44	47	29	84	11	43	43	
Group 7								
TF103	52	47	19	100	11	48	46	
TF106	44	47	29	87	11	44	44	
TF112	44	47	29	87	11	44	44	
TF118	15	63	69	21	44		42	43
Group 8								
TF120	8	27	12	88	44	36	36	
TF121	8	27	13	88	44	36	36	
TF122	44	27	12	91	11	40	37	
Group 9								
TF124	15	27	12	69	44	35	33	
TF125	15	27	13	69	44	35	34	
TF126	52	27	12	72	11	39	35	
Group 10								
TF128	15	63	69	21	44		42	49
Group 11								
TF130	8	63	58	27	44		40	43
TF131	44	63	58	30	11		41	48

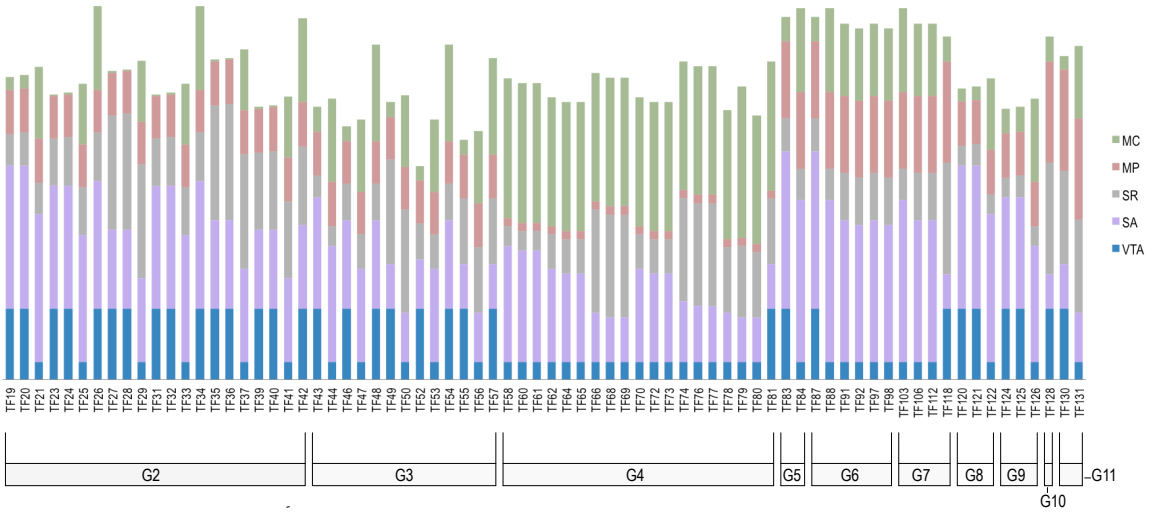

Figure 5.18 – Solutions to be discarded: weighted evaluations under five criteria

The overall scores of the three design-related scenarios are shown in the *overall thermometers* shown in *Figure 5.19* and listed in the *Appendix D.4*.

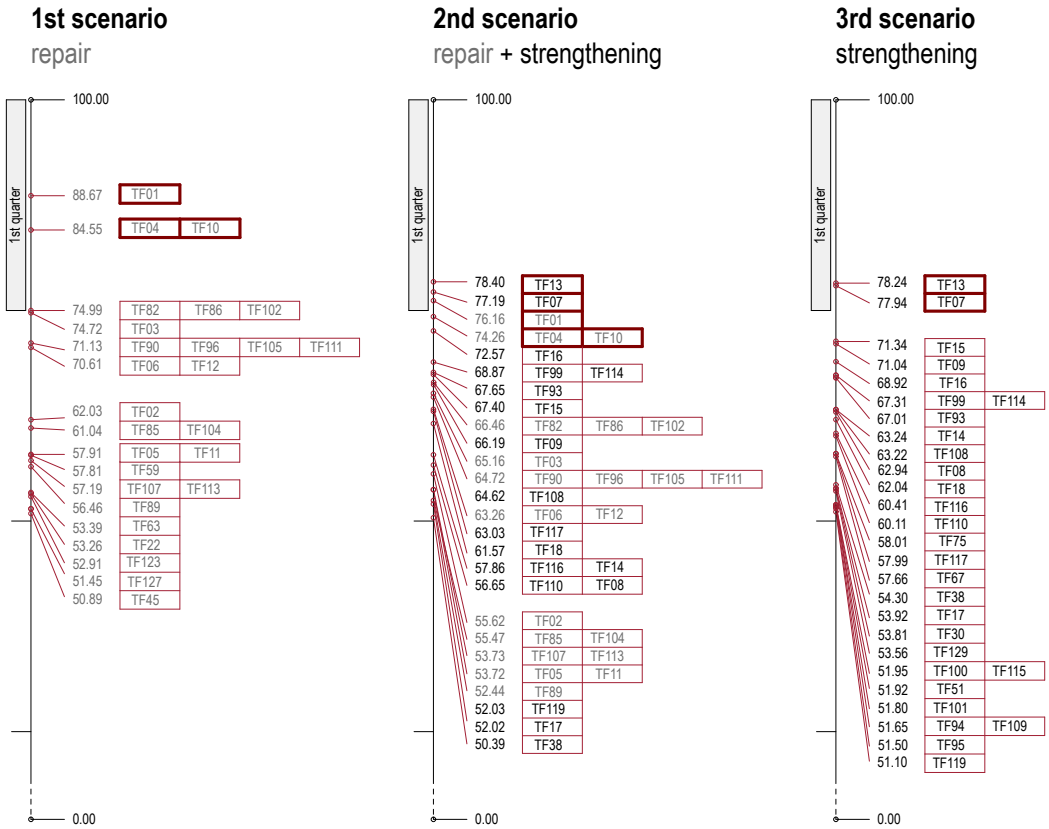

Figure 5.19 – Visual scoring: 1st, 2nd, and 3rd scenario (*repair* in grey and *strengthening* in black)

The high weighting attributed to material compatibility (MC) in all scenarios (*Table 5.10*) results in the best-scoring solutions which all belong to *Group 1* (*Figure 5.20*).

From the comparison of all best-scoring solutions of three selected scenarios, a predominance of five solutions follows (*Tables 5.14*, *5.15*):

- *F+I*: substitution of decayed timber elements with autoclaved timber components; partial infill removal with brick repair or rubble masonry, or infill replacement using clay bricks (or roof tiles) grouted with hydraulic lime mortar;
- *J*: repair measures, i.e. recovery existing carpentry joints by using wooden pegs and pins or replacement with stainless steel nails; or strengthening measures, i.e. using self-tapping screws plated with stainless steel bolts or NSM (steel, CFRP or GFRP bars);
- *S*: mono or multi-layer plaster based on NHL or lime-based render reinforced by fiberglass mesh.

Table 5.14 – Best-scoring solutions obtained by Macbeth analysis

<table>
<tr><th rowspan="2">Intervention</th><th rowspan="2">Aim</th><th colspan="3">Sub-type of intervention</th></tr>
<tr><th>FRAMEWORK+INFILL (F+I)</th><th>JOINTS (J)</th><th>SURFACE FINISH (S)</th></tr>
<tr><td>TF01</td><td>repair</td><td rowspan="5">F1: Substitution of local decayed timber elements with autoclaved timber components
+ either
I1: Partial removal of infill and repair of the brick or rubble masonry
or
I2a: Replacement of infill using clay bricks (or roof tiles) and hydraulic lime mortar</td><td>J1a: Recovery of carpentry joints using: wooden pegs and pins or
J1b: stainless steel nails</td><td rowspan="5">S1a: Mono or multi-layer plaster by using NHL- based and/or lime-based render reinforced by fiberglass mesh</td></tr>
<tr><td>TF04</td><td>repair</td><td>J2a: Strengthening carpentry joints using stainless steel bolts</td></tr>
<tr><td>TF07</td><td>strengthening</td><td>J2b: Strengthening carpentry joints using stainless steel plates with bolts</td></tr>
<tr><td>TF10</td><td>repair</td><td>J2c: Self-tapping stainless steel screws</td></tr>
<tr><td>TF13</td><td>strengthening</td><td>J2d: Strengthening carpentry joints using NSM (steel bars or FRP bars)</td></tr>
</table>

These five best-scoring solutions consist of similar interventions on timber framework, infill, and surface, whereas they differ on four types of intervention for the joints. Therefore, under the same interventions on the wooden components and surface finish, additional criteria can be taken into account for the comparison of these best solutions, i.e. the average costs[133] and time required to repair or strengthen the joints.

A proper carpentry joint recovery can be carried out only by an experienced timber framer by drilling peg holes and using wooden pegs and pins (draw boring). Additionally, repair procedures are quite time demanding. Recourse to bolts or self-tapping screws can save time and keep costs low (not more than € 12 per wall), whereas the use of steel plates, although not time-consuming (the application can be accomplished in one day), substantially increases the costs (approximately € 130 per wall). Lastly, retrofitting performed with NSM steel flat bars is somewhat more affordable than steel plates (around € 100 per wall), yet it takes 8 days to retrofit one wall (1 day for opening the slots and 7 days to apply the glue and let it dry). Precise workmanship is required to open the slots.

[133] In absence of relevant differences in terms of cost from 2013 until now, information related to the financial and data costs was referenced from Poletti's PhD thesis (Poletti, E. 2013, 173).

Table 5.15 – Best-scoring solutions: weighted evaluations under five criteria in three-design scenarios

	Partial Evaluations					Weighted Evaluations		
	Criterion					Scenario		
Intervention	MC	MP	SR	SA	VTA	1st	2nd	3rd
Group 1								
TF01	100	61	19	100	100	89	76	
TF04	93	61	29	87	100	85	74	
TF07	93	61	70	60	100		77	78
TF10	93	61	29	87	100	85	74	
TF13	93	61	70	66	100		78	78

Once the decision-making process has been concluded, the following questions can be addressed:

1. Do similar scores exist in the same group of alternatives?

The 131 combinations of techniques (*Table 5.04*) are listed according to the different interventions on the structure wall (*F+I*). The other two components of the timber frame wall (*J*, *S*) are thereby selected depending on the type of *F+I* (*section 5.3.4*).

For this reason and due to the high importance attributed to *F+I* in four out of five criteria (42% in MC; 56% in MP; 35% in SR; 45% in SA, *Table 5.09*), all solutions are expected to reach consistent value scores within the same group. More specifically, *Group 1* (G1) includes the solutions with the higher scores (*Figure 5.20*), whereas almost all of the worst-scoring solutions belong to *Groups 9*, *10*, *11*.

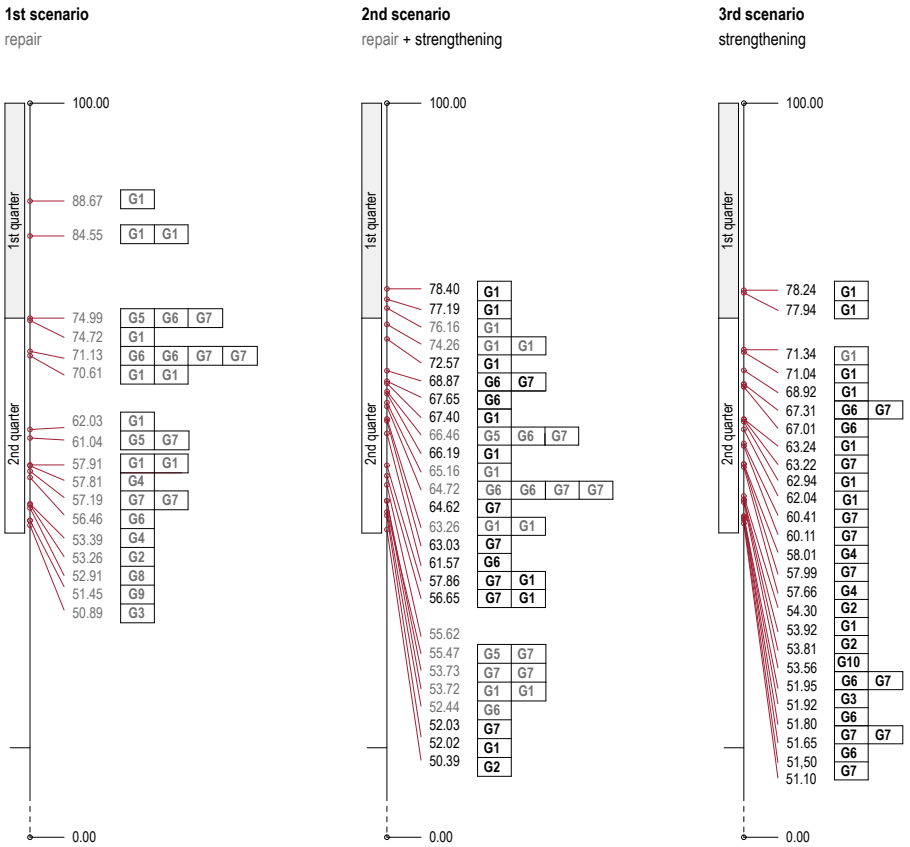

Figure 5.20 – Visual scoring of the best-scoring solutions and their respective *Group* (G)

2. From the different standpoints within the group of experts, which alternatives are expected to score best?

The expected best-scoring alternatives for each group of experts, with the respective scores processed by Macbeth, are almost entirely different depending on the field of expertise.

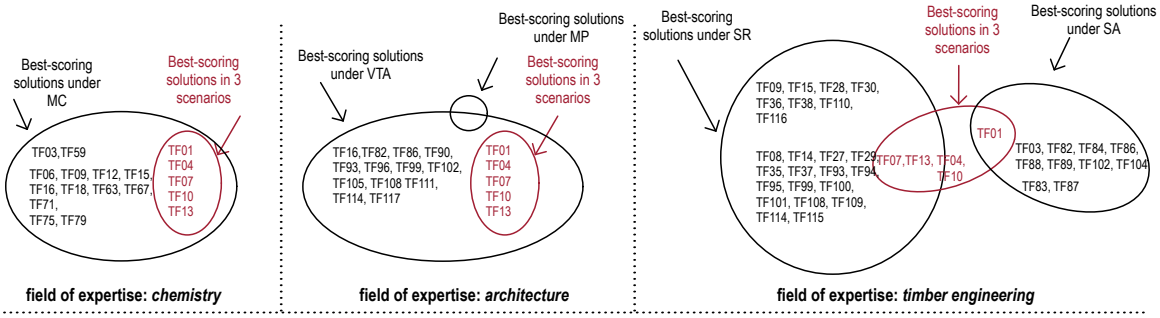

Figure 5.21 – Expected best-scoring solutions from different fields of expertise

A comparison of the 1st quarter of the best solutions and the expected best-scoring alternatives, which reflect the experts' preferences (value scores >70/100, *Table 5.16*), shows that most of Macbeth's results were predictable, especially for the chemist and architect groups. We can note that the best-scoring solutions for MP criterion do not reach 70/100, because all the analysed solutions involve surface removal (*Figure 5.21*, *Table 5.16*).

Table 5.16 – Expected best-scoring solutions from the different experts' standpoints

Criterion	Intervention	Value Score > 70/100
MC	TF01, TF03, TF59	100
	TF04, TF06, TF07, TF09, TF10, TF12, TF13, TF15, TF16, TF18, TF63, TF67, TF71, TF75, TF79,	93
	TF02, TF58, TF60, TF61	86
	TF05, TF08, TF11, TF14, TF17, TF62, TF64 - TF66, TF68-TF70, TF72-TF74, TF76-TF78, TF80, TF81	79
chemistry		

Criteria	Intervention	Value Score > 70/100
MP	-	-
VTA	TF01, TF04, TF07, TF10, TF13, TF16, TF82, TF86,TF90, TF93, TF96, TF99, TF102, TF105, TF108, TF111, TF114, TF117	100
architecture		

Criterion	Intervention	Value Score > 70/100
SR	TF09, TF15, TF28, TF30, TF36, TF38, TF110, TF116,	71
	TF07, TF08, TF13, TF14, TF27, TF29, TF35, TF37, TF93, TF94, TF95, TF99, TF100, TF101, TF108, TF109,TF114,TF115	70

Criterion	Intervention	Value Score > 70/100
SA	TF01-TF03, TF82, TF84-TF86, TF88, TF89 TF102-TF104	100
	TF83, TF87	97
	TF21, TF22, TF122, TF123	91
	TF19, TF20, TF10,TF121	88
	TF04 -TF06, TF10 -TF12, TF90, TF91, TF96, TF97, TF105 -TF07, TF111-TF113	87
	TF92, TF98	84
	TF25, TF26, TF33,TF34	78
	TF23, TF24,TF31, TF32	75
	TF44, TF58, TF126, TF127	71
timber engineerig		

3. What are the greatest advantages and drawbacks of using Macbeth or other multi-criteria analysis tool in the domain of the built heritage rehabilitation?

In this research, Macbeth was employed not only for the assessment of different interventions under five criteria, but was also used for structuring the weighting of interventions depending on the type of timber frame wall component (*Figure 5.13*) and the value tree related to different scenarios (*Figure 5.14*).[134]

The benefits of using Macbeth analysis are the involvement of multi-disciplinary experts and the possibility of evaluating different options under tailor-made parameters for the domain of cultural heritage, i.e. non-numerable, non-homogeneous, and conflicting criteria. Experts frequently have difficulty assigning a direct numerical value to the weightings of criteria and their performance levels. As shown in this research, they feel more comfortable in making comparisons through semantic judgments by expressing the importance (or attractiveness) of preferences between every element of evaluation.[135]

The goal is to reach a consensus within a group of experts, some of whose standpoints are conflicting, by fostering a debate during the attribution of semantic value to the difference between each pair of attributes.

4. Can a compromise be found between multiple and conflicting aims and practical solutions in current rehabilitation works?

The five best-scoring solutions identified in *Table 5.14* integrate standpoints and preferences of a multi-disciplinary panel of experts within three design-related scenarios. Balancing a variety of criteria, these solutions can be recommended by the technicians to the building owner and finally employed by the contractors.

[134] In short, the following Macbeth models were built in order to obtain research outputs: four models for defining the difference of attractiveness between the performance levels of four criteria (*Figures 5.11*, *5.12*), five models for defining the difference of attractiveness between each timber frame wall sub-component in each criterion (*Figure 5.13*). The overall outputs (weighted evaluations) were then introduced into three Macbeth models, each corresponding to a differently weighted set of criteria (i.e. scenario design-related models) (*Figure 5.14*).
[135] (Bana e Costa, C.A. 1988) (Bana e Costa, C.A. 1992)

5.4.5 Research limitations and forthcoming perspectives

The main limitations of this research concern:

- problem structuring: time-consuming procedure, poor interoperability, and interface;
- scope of application;
- gaps in scientific understanding (or dissemination of experimental data) related to the original components;
- potential disconnect between the evaluation in theory and the real result of the interventions (arising from questions of quality of workmanship).

(i) This analysis is carried out by creating separate models with the aim of including a large amount of information gathered by a group of experts over several years. Problem structuring is time-consuming due to the large number of inputs. Moreover, Macbeth lacks sufficient interoperability with Excel: the analyst is not able to import these data directly from Excel and thus it involves extra work. Neither is it possible to save data in Excel via Macbeth. In addition, the graphical user interface should be improved so as to be able to display graphs of adequate resolution. On the other hand, the fast processing of the outputs makes it feasible to re-run the analysis while varying specific inputs.

(ii) The experts are evaluating the impact of a set of interventions on a single construction component whose behaviour actually depends on the global performance and interactions of other members. The experts' judgments are affected by uncertainty around the real configuration of this composite system.

(iii) Despite a considerable scholarly interest in this type of wall and the current need to recover timber-framed buildings in several countries (including Portugal), several knowledge gaps can still be identified. Experts' uncertainty arises from a lack of information related to the impact of the combined rehabilitation measures of all sub-components of the timber frame wall (e.g. interface phenomena). Recent laboratory campaigns in Portugal on un-reinforced and reinforced tested specimens of TFW clarify the influence of the infill and the effectiveness of the interventions on the joints in the mechanical behaviour but do not provide sufficient data as regards the interaction of the structure wall (*F+I*) and the surface finish (*S*) under static and cyclic loadings. As matter of fact, the placement of surface finish on the specimens was completely neglected in these frame tests, although an increase of the stiffness and of the mechanical strength of the whole system can be induced by a simple modification of the surface finish thickness. Conversely, the seismic performance of plastered timber frames of traditional Turkish buildings (*himis*[136]) under reverse-cyclic loading was evaluated by Aktaş and Turer.[137]

While the performance descriptors and performance levels of each criterion (*Table 5.08*) are defined on a sound basis, the assignment of the weighting of sub-components for each criterion (*Table 5.09*) was a more complicated task. For example, the weight of *Framework and Infill* (*F+I*) in the evaluations under SR criterion was evaluated 0.35 (*Table 5.09*). This reflects the combined influence of the type of framework and infill in the overall

[136] *Hımış* houses are made of ground floor of a masonry, that may or may not be timber-strengthened, and upper floors composed of a timber frame load-bearing system (Langenbach, R. 2009). The geometry of timber frame walls, the infill and surface materials greatly varies and these solutions are different from the Portuguese systems.
[137] (Aktaş, Y.D.; Turer, A. 2016)

behaviour.

This lack of information (or dissemination of experimental data) induces uncertainty in the evaluations of the rehabilitation techniques, especially under MC and SR criteria. Due to the great variability of infill, from brick masonry to rubble masonry to mud, it is difficult to homogeneously assess infill characteristics. Other issues arise from difference between the replaced materials and the original components, even in case of repair with rubble masonry and lime mortar. The original masonry mortar was aerial lime and thus weaker than the hydraulic mortar that was included as possible replacement material for *I1* and *I2a*. As underlined by Lopes, the comparison between several analytical and experimental results – those obtained in the Laboratory test at LNEC in 1997[138] – show that the stiffness of TFW is overestimated in the experimental analysis.

(iv) Additionally, experts' evaluations are probabilistic. These concern ideal solutions and thus neglect several factors that may occur at the work site, one of which is related to the quality of workmanship. In fact, as noted by Aktaş and Turer for traditional timber-framed systems in Turkey[139] and also valid for this case study, the quality of workmanship strongly influences the reliability of the intervention for the lateral load-displacement relationships and for the overall behavior of the wall. These scholars observe a variation in quality for work done even by the same group of builders on a limited set of frames. In particular, the quality of the connection (e.g. number of nails at each connection and their driving angles), which influences the strength and stiffness, may vary from frame to frame within the same wall. Poor construction,[140] lack of proper reinforcement in the joint region, or lack of proper infill geometry can cause brittle failure mechanisms at the local level. This makes it difficult to generalize the findings of these frame tests, and thus may affect the objectivity of the evaluation under the SR criterion.

Regardless of these aspects, the novelty of this research is two-fold. Firstly, it provides a systemisation and bundling of the current intervention techniques for traditional timber frame walls (TFW) from an extensive survey; secondly, the question of the best rehabilitation techniques for the traditional timber frame wall is examined under a variety of criteria. Furthermore, this procedure is seldom applied in the domain of the civil engineering and built heritage; the ultimate aim of this research is to find a compromise between the architectural and engineering realms – striking a balance between authenticity and structural reliability – and to promote a worthwhile debate between experts in different fields of conservation science.

Although built heritage conservation demands a multi-disciplinary approach and involves multifaceted cultural and economic value, the current practice is largely determined by the requirements or preferences of relatively few decision-makers. As an alternative, a well-informed, interactive, and transparent procedure is called for.

To this end, this research includes the involvement of multi-disciplinary experts in conservation sciences throughout all phases of problem structuring (*Figure 5.22*).

The forthcoming applications of this model are extremely challenging. Macbeth analysis could support the decision-maker in a critical appraisal of a large spectrum of practical solutions, e.g. different interventions on other types of structure walls of braced timber frame buildings (i.e. masonry reinforced with timber frames, rubble store

[138] (Santos, S. P. 1998) (Lopes, M. 2012)
[139] (Aktaş, Y.D.; Turer, A. 2016)
[140] "Poor construction" means "poor material quality, poor seasoning, poor treatment, poor detailing, alterations of design" (Serafini, A.; Riggio, M.P.; González-Longo, C. 2017, 7).

masonry or partitions walls).[141] Furthermore, this methodology can be applied to other scenario models that embrace different requirements of the owners or users (e.g. energy saving and cost effectiveness). Adding other evaluation criteria will increase the timing of the analysis. In order to be able to manage the decision analysis results and reduce the time of the model construction, the number of evaluation criteria should not exceed nine.[142]

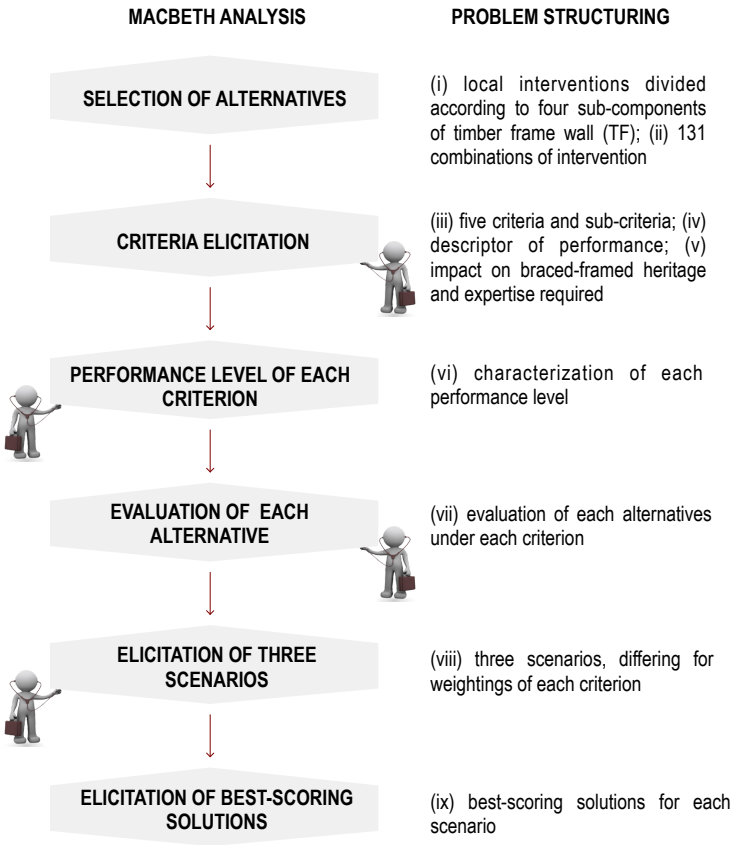

Figure 5.22 – Problem structuring and involvement of a panel of expert (© S. Stellacci)

[141] These different walls are analysed in *Chapter 4*, *section 4.3.3.1*.
[142] (Roszkowska, E. 2014)

5.5 Final comments

The decision-making process related to the built heritage is commonly affected by conflicting instances arising from distinct users' demands, code-required actions, and the need to preserve the cultural significance of the construction.[143] Thus, the selection of proper interventions on the whole building (or on its construction components) can be a complex task.

A general framework of buildings in downtown Lisbon was discussed by unraveling the main factors and strategy priorities that can influence the current intervention. Buildings, investors/users, and technicians were analysed as key factors within the decision-making process of the rehabilitation of *Pombalino* buildings. Due to the relevant cultural value of this type of constructions, even in case of private ownership – as it is the case of the majority of this building stock – each intervention should be approached through a transparent and interactive process. The technicians should select the more appropriate solution as a compromise of safety conditions and other code-required actions together with the customer's budgetary constraints and those related to the occupancy of the building plots. Even if it essential to consider these priorities, the cultural value of the building (in which the action is required) should be of the utmost importance.

After outlining this framework, the scope of application was narrowed down by focusing to a key component of timber frame construction, the internal load-bearing wall, in order to draw attention to the impact of specific rehabilitation techniques upon the buildings.

Different rehabilitation solutions for timber frame walls were identified and critically evaluated by experts of the conservation science under multiple criteria by dedicated software (M-Macbeth, *Measuring Attractiveness by a Categorical-Based Evaluation technique*). 131 combinations of techniques, used as inputs for this analysis, are chosen based on an extensive survey covering current practice and experimental tests, and identified for four construction sub-components of this load-bearing wall, i.e. timber framework, infill, joints, and surface finish.

The main principles of conservation science were synthetized into five evaluation criteria, i.e. material compatibility and material permanence, structural reliability and structural authenticity, and visual-tactile appearance. Performance descriptors, evaluation levels, and weightings of these criteria were also defined by a multidisciplinary panel of experts (i.e. chemists, timber engineers, and architects).

An interactive decision process, based on the knowledge of a joint team, was thus set up. Three scenario models will be chosen by the decision-makers (owners or dwellers) according to the state of the building – state of conservation and structural performance – prior to the intervention are thus characterized by different weighting factors of each criterion. In this context, the material compatibility is a most important criterion in every scenario model, since it is related to the durability and the effectiveness of the works. The visual and tactile appearance, the material permanence and the structural authenticity play an important role especially when the integrity of the historical building has been preserved over the time (1st scenario). The majority of *Pombalino* buildings can be included into the 2nd scenario, where the same weighting is attributed to each criterion. Conversely, the structural reliability, that is a priority in seismic prone regions with densely populated areas, is the first criterion in cases of heavily damaged or degraded buildings (3rd scenario).

Results clearly show that Macbeth is a useful decision-aid capable of handling multiple outputs generated

[143] (Pedro, J.B.; Campos, V. 2016, 254)

from qualitative expert judgments.

More specifically, Macbeth outputs show that the best-scoring solutions of all of the three scenarios imply the removal of local decayed timber elements and the replacement in kind with autoclaved timber components (*F1*), the partial removal of infill and repair of the brick or rubble masonry (*Ia*) or the replacement of infill using clay bricks (or roof tiles) and hydraulic lime mortar (*I2a*), and mono or multi-layer plaster by using NHL-based and/or lime-based render reinforced by fiberglass mesh (*S1a*).

The main limitations of this research were identified during the problem structuring and throughout the assessments of the rehabilitation techniques influenced by a lack of adequate specific information (or dissemination of experimental data) related to the original components and by the quality of workmanship, which may significantly affect this analysis. While some aspects about the seismic performance of TFW are well understood, further researches are still required particularly related to the impact of different surface finish on the overall behaviour.

Regardless of these research limitations, this procedure allows to increase the consistency, transparency, and legitimacy of the decision-making process. The results encourage further in-depth research by using this method with the aim to support other decision problems related to the rehabilitation of historic buildings and solve conflicting situations as well increase the awareness of the agents involved.

This research can be extended to other timber-framed constructions in different geographical and cultural contexts, because the timber frame wall is as a timeless golden thread of the anti-seismic heritage in the Mediterranean basin (and not limited to it). Furthermore, this methodology can be applied to inform future practice and research related to other traditional construction systems and scenario models that embrace different requirements of the owners or users, e.g. energy saving and cost effectiveness.

CONCLUSIONS

Two centuries have passed since the dredful earthquakes of 1755 and 1783 – about six generations of political, cultural, and economic vicissitudes. Surfaces have been cracked by time, often covered or destroyed; interiors have seen different households, changing habits and customs; the roads have been traveled by carriages, then by cars and later again only by pedestrians. Functions and different conceptions have left their overlapping marks. Collective and personal events have acted on these post-earthquake reconstructions, by which mere *urban transplants*[1] have since become *historical* urban tissue.

While the natural causes which trigger seismic events continue to be studied, above all trying to outline a seismic storyline which may be repeated, the historical reactions of communities and local authorities have been the subject of extensive research and interest for years. Lisbon's reconstruction closed the doors to the *ancien Régime*, entering the modern era in full force; the literature on this is vast, cataloguing countless interacting valences.

Much has also been written and debated on the Calabrian post-earthquake reconstruction in the last years, especially after seismic events in the 20th century unfortunately re-opened dark chapters that had seemed closed. More so than many written pages, the iconographic documents capture the effects of a force as devastating and unexpected as that of the 18th century earthquakes,[2] just as photographic documentation has recently done in L'Aquila and Amatrice.[3]

This thesis strives to consider the topic from multiple angles, trying to establish patterns of analogies and divergences between the Portuguese and the Italian events as well as retracing the different ways in which the central powers built according to new or existing trajectories.

The comparative analysis between the two geographical contexts inevitably branched into insights into *Pombalina* Lisbon in comparison with pre-*Pombalina* Lisbon, and *Borbone* Calabria with its previous state. Following paths already partly traced in their respective contexts, the analysis of *Pombalina* Lisbon and *Borbone* Calabria was further doubled by comparing the planned *vs* the executed, considering the latter in relation to its current condition.

There were therefore many points discussed and many questions brought into sharper focus, such as the continuity over the centuries of timber-framed constructions in Portugal and in the south of Italy, the typological layout

[1] Term employed by Principe in regard to the Calabrian rebuilding (Principe, I. 1976, 375).
[2] The Calabrian landscape after the 1783 events was dramatically represented in the 51st plates of Vivenzio's *Atlas* (Vivenzio, G. 1788). These pictures were marked by few terrified post-earthquake survivors pointing towards enormous circular lagoon depressions, barren hills carved in the shape of an amphitheatre, piles of stone and wood, and overturned trees. See (Keller, S.B. 1998).The same indelible marks were found and retraced in the short film *Atlante 1783,* directed by Cicciari in 2016.
[3] (Maggia, F.; Serra, T. (eds.) 2017).

and architectural analysis of Calabrian *case baraccate*, and the effectiveness of repair or strengthening techniques applied to traditional timber-framed constructions.

According to Francastel, the significant historical phase related to three Enlightenment cities, defined as products of *Reason* – Turin, London, Copenhagen – would be concluded with the rebuilding of Lisbon.[4] Our research extends this outlook by two decades, concluding with the *Borbone* reconstruction in the southern provinces of the Neapolitan Kingdom.

An important point adressed in this research regards the influence of the *Pombalino* system upon the Calabrian one. Practical technical awareness about the earthquake damage were observed in Portugal as well as in the Italian peninsula, existing long before news of the great Lisbon earthquake. Indeed, analysis of the building practice in Calabria during the 16th and 17th centuries might shed light on this controversial question and disprove the fundamental role of the Portuguese response in the Calabrian phase. Traditional timber-framed houses existed for many centuries in southern Italy long before Sarconi's survey campaign under the aegis of the *Borbone* governament, when concern about earthquakes was already one of the influential factors in the choice and diffusion of local construction systems, together with economic feasibility (cost and availability of materials), the technical skills available, and the needs of those who would occupy the buildings. However, the presence of ancient timber-framed buildings does not disprove the influence of the Portuguese reconstruction phases on the *Borbone* governmental model, especially considering the wide cultural exchange in this epoch.

Late 18th century anti-seismic structures in both contexts assume a meta-historical value. This is in common with other seismically-prone regions – especially the Greek and Turkish ones – where the development of similar construction techniques was accompanied and determined by the collective effort to efficiently withstand seismic impact. We were impelled to go back further, deepening the analysis of the most cited case, that of ancient Herculaneum, by looking at the archaeological site for comparative purposes with later Portuguese and Calabrian buildings (*prédios pombalinos versus case baraccate*).

We shall briefly retrace the steps taken throughout this work-study on the timber frame walls, which can be viewed as a sort of triangulation between the ancient Roman, Portuguese, and Italian technical cultures. Additionally, although the priority thematic area of research was centered upon the late 18th century post-seismic activities, this investigation is not confined to a single time-period.

In the first part of this thesis (*Chapter 1* to *Chapter 4*), it was shown how the pervasiveness of the timber frame wall arises from manifold reasons. Various aspects related to human/environment interactions favoured the use and dissemination of this technique in seismic prone areas. The advantages of this technique, interpreted as *trait d'union* of the craftsmen's skills and the users' requirements, were analysed in a distant yet noteworthy context, the Vesuvian towns encased in volcanic ash. It was shown that the pragmatic approach prevailed in the post-earthquake reconstructions after 62/63 AD. In fact, in some cases *craticii parietes* were executed to split tiny rooms, or to add floor space by executing additional upper floors other dwellings. Archaeological findings clearly show that Romans developed an empirical understanding of the principles of dynamics, probably based on post-analysis of the seismic

[4] (França, J. A. 1987, 10)

damage. However, this physical evidence – even if heavily damaged by the underground *Borbone* tunnels and later altered by Maiuri's works in 1930s – suggested that the greatest reason underpinning the use of timber frame wall (especially in the upper floors of the houses) was to take advantage of a swift and light construction solution. In fact, in cases of internal timber frame walls, the thinness of the partitions allows the limited floor space to be more easily organized. Then, *craticii parietes* were completely hidden by figurative frescos or by plain white plaster in a such way that it was not distinguishable from brick-concrete faced surfaces. In some cases, such as in *Collegio degli Augustali* (*College* or *Shrine of the Augustales,* VI, 21) at Herculaneum, the timber frame wall was executed in a second phase, after the construction of the floor and roof, for a subsidiary function, thus as simple partition in order to subdivide the interior space.

Conversely, many centuries later, the use of timber-framed systems in Lisbon (as well as in the territories of Portuguese jurisdiction or influence) and Calabria sought *terraemotus damna impedire*, that is, to prevent the huge loss of life and large-scale building damage. Empirical observations of the structural reliability of vernacular timber framed buildings in the late 18th century earthquakes set the course of a new science: anti-seismic engineering. In fact, analysis of Portuguese and Italian traditional constructions prior to this time shows that the technicians of the respective governments did not subsequently devise an *ad hoc* construction solution but sought to improve upon references in their own local history. In Lisbon, it was shown that one of the most interesting physical and technical continuities between the pre- and post-earthquake city is embodied in a specific type of timber-framed dwellings: the overhanging houses (*casas de andares em ressalto*). The analysis of this building type, including a census of still standing examples in Lisbon, was contextualized by referring to the legislative provisions issued in the 15th and 16th centuries for functional and safety purposes, as well as for aesthetic improvements of the steadily growing city. In the central and southern regions of Italy, including Calabria, single timber-framed edifices or outbuildings of the palaces were executed as anti-seismic shelters. Evidence of pre-1783 timber-framed buildings was provided by eyewitness accounts of the late 13th century, and later by on-site surveys among the debris and rubble of the Calabrian towns.

Pombalino Lisbon (post-1755) and numerous rebuilt towns in Calabria (post-1783) represent the field of application of a set of pioneering measures for the improvement of building safety and living conditions. Incorporated in urban layouts drawn by ruler and set square, these anti-seismic constructions testify to the extraordinary disaster-response strategies that influenced planning practice and technical knowledge across Europe.

In addition to the typical pragmatism of the enlightenment period, *Pombalino* and *Borbone* systems were based on an understanding of seismic efficiency reached through the interlocking of each building block and its components and on interpretation of the classical rules of composition. Regardless of the different scales of these interventions and their physical legacies, the post-seismic heritage of the late 18th century was the product of the rapid response of the central authorities who delegated implementation of reform to the military intelligentsia. Although the post-seismic rebuilding in Calabria shows symptoms of the conflict between the rationalistic-institutional culture and the historical-environmental culture, the anti-seismic building stock of this phase is worthy of attention.

Narratives of a private building in downtown Lisbon (1780-1789) and the Bishop's Palace of Mileto (1784-1795) were discussed to illustrate the complex processes of healing the scars of the respective cities. Included into a regular grid plan conceived *ex-nihilo*, these case studies are characterized by symmetry, regularity, and analogous

construction systems of a load-bearing timber skeleton filled with heterogeneous materials and connected to the other construction components of the buildings (e.g. vertical posts to floor and roof structures). All of these characteristics contribute to effectively counteract and metabolise shearing actions.

The description of these selected constructions and their histories might interest a wider readership generally not given the opportunity to see these building structures revealed. This graspable memory may represent a vehicle for a closer relationship to the past and the re-appropriation of their own local culture.

Since the architectural and structural features are crucial to the seismic response of these building stocks, they should be safeguarded for their technical and cultural value. Once the *active preservation* of traditional timber framed buildings is recognized as imperative, it is necessary to question the impact of current practice in order to reveal the risks of intrusive or improper interventions that weaken seismic performance and put the built heritage and collective memory it embodies at risk of loss.

The history of earthquakes has often been a history of lessons ignored – building blocks fragmented, extra floors added, interiors demolished, symmetry broken.[5] New urban planning and historical renewal therefore cannot fail to reflect on the importance of principles underpinning late 18th century post-seismic reconstruction. With a view towards more restrictive legislative provisions, it is important to highlight the multiple weaknesses inflicted on this analysed heritage by neglect or by intrusive and inappropriate rmeasures taken on it.

Recognising the importance of preserving physical evidence of these traditional construction structures and of guaranteeing minimum safety levels of their inhabitants, the aim of the second part of this thesis (*Chapter 5*) was to assess the current rehabilitation techniques for its key load-bearing component – the timber frame wall (TFW). This problem-solving process was carried out by a multi-criteria model through M-Macbeth software, based on the translation of qualitative value judgments into cardinal scores.

Different repair or reinforcement techniques were selected depending on the state of conservation of the constructions, their degree of authenticity, and their target level of safety. Ranging from more conservative to more intrusive approaches, this set of alternatives was extrapolated from an extensive literature review on current practice and experimental results. Under specific conditions of TFW – retrofittable and lacking the original surface finish – different rehabilitation techniques were identified for four sub-components (framework, infill, joint, and surface finish), ranging from traditional methods to innovative materials and new methods. 131 possible combinations were found and regrouped in eleven groups based on the type of the intervention on the wall structure. These combinations were selected with the aim of grouping homogeneous solutions, which entail reasonable economic and practical feasibility, i.e. minimum workmanship required and number of material types. Once catalogued, these solutions were evaluated by a group of experts under five criteria: material compatibility, material permanence, structural reliability, structural authenticity, and visual-tactile appearance. The panel of experts was composed of specialists from fields related to

[5] As assumed by França, the temporariness of public strategies aimed at reducing earthquake damage was understood by Manuel da Maia himself while describing the initial proposal for rebuilding Lisbon, based on the maintenance of the former urban tissue: "[I]t should be noted that Maia does not believe that such precautions [against other catastrophes] can be observed for a long time: human greed or vanity, or perhaps the law of forgetfulness, will prevail." *Pt*: "[É] preciso notar que Maia não acredita que semelhantes precauções [contra outras catástrofes] possam ser observadas por muito tempo: a avidez ou a vaidade humana, ou, talvez, a lei do esquecimento, hão-de prevalecer." (França, J. A. 1987, 80)

conservation science of historical buildings, i.e. chemistry, timber engineering, and architecture. It is essential to underline the value of multi-disciplinary experts for setting up a well-informed and transparent procedure. Under the coordination of the analyst (the author of this thesis), this panel of experts was involved throughout all phases of the problem structuring, i.e. definition and weights of evaluation criteria, evaluation of alternatives, and research refinement. Grounded on a set of data collected through academic and work site research, experts' evaluations, although subjective, played a crucial role in the decision-making tool.

The outputs consist of reduction of eleven groups of alternatives to a few best-scoring solutions within three different scenarios, differentiated by the weights of each criterion.

The novelty of this multi-criteria analysis arises from the scarcity of applications of an objective methodology in decision-making for built heritage issues. In fact, although built heritage conservation demands a multi-disciplinary approach and involves multifaceted values, the current practice – as visible in *Pombalino* buildings of downtown Lisbon – is often dictated by the demands of few stakeholders. For the sake of cultural continuity in local communities, a fuller understanding and dissemination of knowledge related to traditional anti-seismic technique is required in order to preserve the identity value beyond real estate market interests. As shown in this research, balancing safety levels and heritage values is a demanding task. While it is a priority to guarantee the safety and satisfaction of the inhabitants, it is also vital to safeguard the permanence of physical and intangible memory enclosed between the walls of the historic buildings.

FUTURE RESEARCH LINES

Possible future research can investigate in more detail some aspects discussed throughout this thematic axis, which was centered around the earthquake-resistant structures in the Mediterranean basin, in the Roman era, and in *Pombalino* and *Borbone* epochs. We suggest some ideas that can inform future research works.

Although the literature on the excavations of the Campanian towns submerged by the volcanic eruption of Vesuvius (79 AD) is vast, further and more systematic study concerning the restored (or reconstructed) archaeological evidence of *craticii parietes* should be developed on the basis of on-site evidence and archival documents. Only the most relevant and well known case of application of this mixed construction technique – *Casa a Graticcio* (*Insula III*, 13-15, Herculaneum) – was critically described in this thesis. Important information on this ancient mixed technique was also derived from on-site surveys and from Andrews's doctoral thesis.[1] The critical analysis of archaeological evidence in the *insulae* of Herculaneum – which is also the topic of *in itinere* doctoral thesis of Laumain – should include a systematic field work and an investigation of the archeological reports (GL and GSE).[2] It should be pointed out that gaining insight into this roman tecnique in these archeological findings is a complex task for two main reasons: firstly, because the authenticity of the mixed walls is strongly compromised by various interventions, especially between 1927 and 1961 under Maiuri's campaign. Furthermore, the access to many buildings, especially in upper floors divided by these mixed walls (e.g. *Casa di Nettuno e Anfitrite*, *Insula V*, 6-7, Herculaneum) is forbidden due to the hazardous condition of their structure.

In regards to the post-1755 reconstruction in Lisbon and post-1783 in Calabria, various aspects of the thesis will be further investigated. Samples of mortar and wood from the Portuguese and Calabrian cases studies can be collected in order to analyse and compare their compositions. These data could integrate information in both contexts, respectively provided by Santos, Ruggieri and Zinno.[3,4] Traditional timber-framed buildings dated prior to the 18th century earthquakes in these contexts clearly needs to be further discussed. More specifically, the overhanging dwellings in Lisbon (pre-1755) can be studied in comparison with those existing in the northern areas of Portugal (e.g. Guimarães, Porto). A census of 18th century buildings in Calabria provinces is also required in order to provide reliable and updated information on the existing stock built with anti-seismic construction system and take this preliminary comparison further.

Another fascinating and promising line of research is related to the application of the multi-criteria methodology in the problem issues of built heritage conservation. As highlighted in the discussion of the results

[1] (Andrews, J.N. 2006)
[2] (Laumain, X. 2013)
[3] (Santos, V.L. 1994)
[4] (Ruggieri, N.; Zinno, R. 2015)

obtained by Macbeth procedure (*Chapter 5*, *section 5.4.5*), some limitations of this research related to the uncertainty of the experts could be approached by robustness analysis. Future laboratory testing might also shed light on the seismic impact varying the type of surface finish and these results might influence the expert' judgments.

Future applications of the Macbeth analysis can support the selection of the best practice for different types of vertical structure of traditional timber framed buildings, i.e. masonry reinforced with timber frames, rubble stone masonry or partitions walls. Moreover, this methodology can be further applied to other types of traditional load-bearing components, and scenario models that embrace different requirements of the owners or users, e.g. energy saving and cost effectiveness. In particular, this latter parameter, which is related to the time to implement the work, the degree of technical job skills, as well as to the cost of supplied materials and components is crucial.

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APPENDIX A

A.1 Extracts from latin literature

Marcus Vitruvius Pollio, De architectura libri decem (*D.a.*)

(II, 8, 20) Craticii vero velim quidem ne inventi essent; quantum enim cleritate et loci laxamento prosunt, tanto maiori et communi sunt calamitati, quod ad incendia uti faces sunt parati. Itaque satius esse videtur inpensa testaceorum in cumptu quem compendio craticiorum esse in periculo. etiamque in tectoriis operibus rimas intus faciunt arrectariorum et transversariorum dispositione. Cum enim linuntur, recipientes umorem turgescunt, deinde siccescendo contrahuntur et ita extenuati disrumpunt tectoriorum soliditatem. Sed quoniam nonnullos celeritas aut inopia aut in pendenti loco dissaeptio cogit, sic erit faciundum. Solum substruatur alte, ut sint intacti ab rudere et pavimento; obruta enim in his cum sunt, vetustate marcidi fiunt; deinde subsidentia proclinantur et disrumpunt speciem tectoriorum. De parietibus et apparatione generatim materiae eorum, quibus sint virtutibus et vitiis quemadmodum potui exposui, de contignationibus autem et copiis earum, quibus comparentur ut ad vetustatem non sint infirmae, uti natura rerum monstrat explicabo.

(II, 8, 20) *ENG.* As for “wattle and daub” I could wish that it had never been invented. The more it saves in time and gains in space, the greater and the more general is the disaster that it may cause; for it is made to catch fire, like torches. It seems better, therefore, to spend on walls of burnt brick, and be at expense, than to save with “wattle and daub,” and be in danger. And, in the stucco covering, too, it makes cracks from the inside by the arrangement of its studs and girts. For these swell with moisture as they are daubed, and then contract as they dry, and, by their shrinking, cause the solid stucco to split. But since some are obliged to use it either to save time or money, or for partitions on an unsupported span, the proper method of construction is as follows. Give it a high foundation so that it may nowhere come in contact with the broken stone-work composing the floor; for if it is sunk in this, it rots in course of time, then settles and sags forward, and so breaks through the surface of the stucco covering.[1]

(VII, 3, 11) Sin autem in craticiis tectoria erunt facienda, quibus necesse est in arrectariis et transversariis rimas fieri, ideo quod luto cum linuntur necessario recipiunt umorem, cum autem arescunt extenuati in tectoriis faciunt rimas, id ut quod fiat haec erit ratio. Cum paries totus luto inquinatus fuerit, tunc in eo opere cannae clavis muscariis perpetuae figantur deinde iterum luto inducto si priores transversarii harundinibus fixae sunt, secundae erectis figantur

[1] (Morgan, M.H. 1914, 57-58)

et ita, uti supra scriptum est, harenatum et marmor et omne tectorium iudicatur, ita cannarum duplex in parietibus harundinibus transversis fixa perpetuitas nec segmina nec rimam ullam fieri patietur.

(VII, 3, 11) *ENG.* But if stucco has to be made on "wattle and daub," where there must be cracks at the uprights and cross-sticks, because they must take in moisture when they are daubed with the mud, and cause cracks in the stucco when they dry and shrink, the following method will prevent this from happening. After the whole wall has been smeared with the mud, nail rows of reeds to it by means of "fly-nails," then spread on the mud a second time, and, if the first rows have been nailed with the shafts transverse, nail on a second set with the shafts vertical, and then, as above described, spread on the sand mortar, the marble, and the whole mass of stucco. Thus, the double series of reeds with their shafts crossing on the walls will prevent any chipping or cracking from taking place. [2]

Gaius Plinius Secundus, Naturalis Historia (*N.h.*)

(XXXV, 48) Illini quidem crates parietum luto et lateribus crudis extrui quis ignorat?

Isidorus Hispalensis, Etymologiarum sive Originum libri XX

(Etym, XIX, 10, 16) Quorum [parietum] crates dicuntur; in quibus lutum pro isdem lateribus crudis portare solent. Sunt enim conexiones cannarum, dicti *apo tou kratein*, id est quod se invicem teneant.

Palladius Rutilius Taurus Aemilianus, Opus agriculturae (*O.a.*)

(1,19, 2) Si terrae pauperes minora promittunt uel craticiis podiis erunt discernenda granaria uel uimineis uasculis redactus tenues congeremus.

I, XI, Quod si latericios parietes in praetorio facere volueris, illud servare debebis, ut perfectis parietibus in summitate, quae trabibus subiacebit, structura testacea cum coronis prominentibus fiat sesquipedali altitudine, ut, si corruptae tegulae aut imbrices fuerint, parietem non possint penetrare perpluvia.

Sextus Pompeius Festus[3]

Pedis subjicitur, sed etiam pro materia robustea, super quam paries craticius exstruitur.

[2] Ibid., 208
[3] (Valpy, A. J. 1826, 877)

APPENDIX B

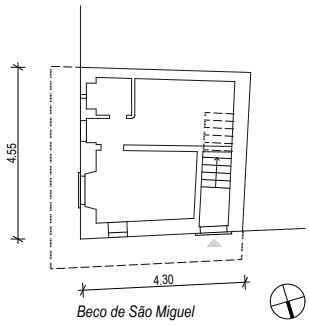
B.1 Collected data on Lisbon's overhanging dwellings

B.1.1 List of Lisbon's overhanging dwellings[1]

Address	Building dossier (AMP, PO)
1. Rua do Espírito Santo, 2; Rua de Sta. Cruz do Castelo, 15	35820
2. Rua do Benformoso, 101-103	33695
3. Rua dos Cegos, 20-22	14279
4. Calçada de S. Vicente, 15-17	21811
5. Rua das Escolas Gerais, 18-20	11051
6. Escadinhas de Sto. Estêvão, 11-13	19343
7. Escadinhas de Sto. Estêvão, 19-21	20273
8. Rua da Regueira, 1-1A	20796
9. Largo do Chafariz de Dentro, 22-23	21713
10. Largo do Chafariz de Dentro, 32-33	10580
11. Calçadinha de Sto. Estêvão, 1-1A; Rua dos Remédios, 25-27	20268
12. Escadinhas de Sto. Estêvão, 1-5; Rua dos Remédios	21285
13. Largo do Chanceler, 3-3A	13102
14. Rua dos Remédios, 63-65; Beco Maria da Guerra, 2	4983, 5344
15. Rua do Vigário, 2-4; Rua dos Remédios, 121	13542
16. Escadinhas dos Remédios, 5-7	32210
17. Beco do Surra, 15-17	11360
18. Rua das Farinhas, 22-26	34975
19. Rua das Farinhas, 32-34	26089
20. Beco das Flores, 23-25	8956
21. Rua da Achada, 9-9A / Largo da Achada, 1	24355
22. Largo de S. Cristóvão, 3-4	33953
23. Pátio da Cruz, 3-4	51666
24. Rua de Castelo Picão, 20-22	21940
25. Rua da Regueira, 37; Beco das Cruzes,1	20857
26. Rua da Regueira, 27-29; Beco da Bicha, s/no. *Demolished*	3861
27. Beco da Formosa, s/no. e Pátio do Prior	34012
28. Rua de S. Miguel, 61-63	20972
29. Beco da Cardosa,10	20584
30. Calçadinha de S. Miguel, 38 *Demolished*	21133
31. Beco de S. Miguel, 15	21582
32. Largo de S. Miguel, 5	17239
33. Beco das Canas, 3-5	13219
34. Rua da Galé, 13-15	3857
35. Beco das Barrelas, 2-4	31891
36. Trav. de S. Miguel, 7-9	3217
37. Largo do Chafariz de Dentro, 16-18	5389
38. Rua João do Outeiro, 9-11	35081
39. Rua da Guia, 1-7	34998
40. Rua do Terreirinho, 51	42666

[1] from *Municipal Inventory of Built Heritage* included in the *Proposal of Detailed Zoning Plan of Urban Rehabilitation of Colina do Castelo* no. 410/2010 (CML 2010)

B.1.2 Technical datasheets of selected case studies



Ground floor plan

Dimensional specification*
ridge height (Hc): 11.80m
ground floor: 4.30 x 4.55m
1st/2nd floor: 5.20 x 4.70m; overhangs: 0.9m; 0.75m
Cantilevered area: 21sqm
**average values*

Location: *Beco de São Miguel* no. 17 Lisbon
Dating: before 1755
Type: Corner building, one apartment for floor
Corrent use: Tourist accommodation
Archival Document: AML, Dossier no. 21582



Elevations

demolition
reconstruction

0 2m

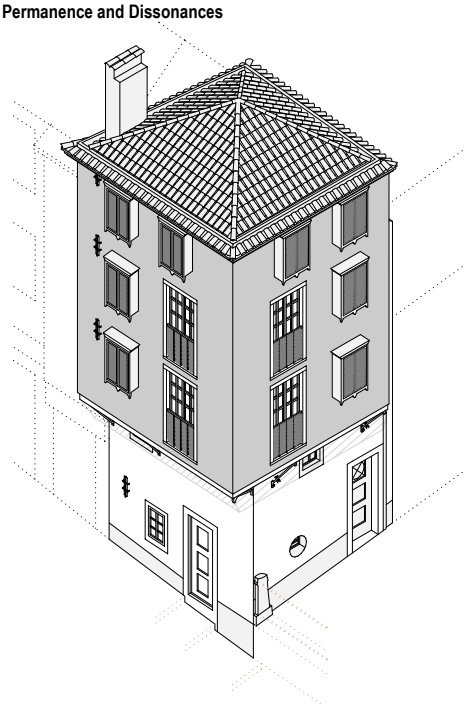
Brief historical note

Located in proximity of *São Miguel* church, this is a bilateral overhanging dwelling on three storeys set on a square plan.
Following a municipal coercive process in 1941, necessary extensive refurbishment works were undertaken. Later, recommendations by the technical supervisor of Lisbon Municipality were disregarded: the alignment of openings, the use of reinforced concrete instead of iron bars to support the balcony and additional finishes, such as a ceramic panel in one of the facades. Structural authenticity was completely lost. During the strengthening works in 1941, the external timber-frame walls on the upper floors were replaced by a reinforced concrete structure, hollow bricks, and cement mortar.
The cantilevered balconies represent a local declination of the Islamic *muxarabi*; however, historical photographs from *Lisbon Municipal Archive* (AML) reveal that the timber balconies are recent. The dark pink facade and the absence of timber planks to protect the overhangs are additional dissonant elements in need of correction.



Archival photograph by unidentified author (1889–1908)

Permanence and Dissonances



Isometric view

original removed element
new construction system
new architectural feature

Construction system
Roofing: Hipped
Exterior wall: Stone masonry on the ground floor; the original timber frame walls filled with rubble stone (on the upper floors) were replaced by hollow bricks.
Floor: The original wooden floors were replaced by concrete slabs.

Degree of structural authenticity: Very low
Degree of architectural authenticity: Low
State of conservation: Medium



Photograph (2016, © S. Stellacci)

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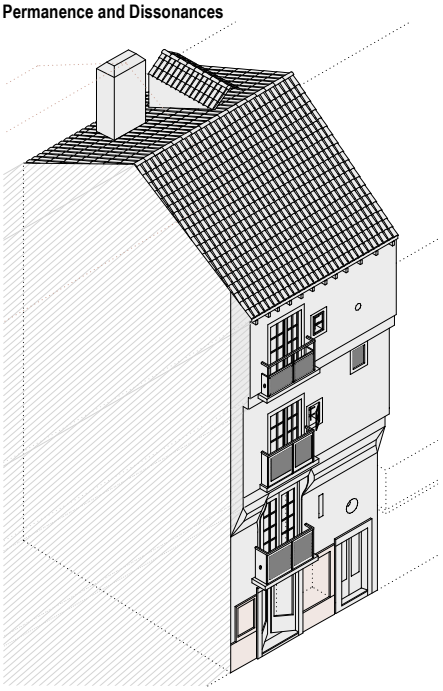
Main elevation

demolition new construction

Permanence and Dissonances

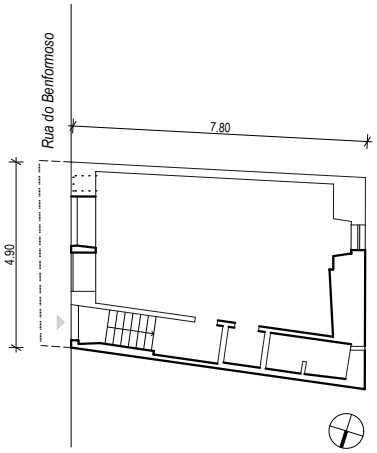


Isometric view

original removed element

new features

original architectural/structural features



Ground floor plan

Dimensional specification*
ridge height (Hc): 13.00 m
ground floor: 4.90 x 7.80 m
mezzanine: 4.90 x 8.30m; overhang: 0.50 m
1st/2nd floor: 4.90 x 8.45m; overhang: 0.15 m
Cantilevered area:
**average values*

Brief historical notes

This double-jetted dwelling is located in the main access to the old city (*Rua do Benformoso*) boosted by trade and procession routes, and surpassed in 1862 by the nearby axis, *Rua da Palma*.

Following the public inspection in 1919, a municipal injunction to demolish the entire building was promulgated due to its structural problems on the upper floors and on the rear facade; however, this provisions was not complied with. The still-standing house is one third of the original block, with shop on the ground floor and a housing on the upper floors. Approved by municipality, two-thirds of the original block were demolished in 1928. The existing building is declared building of public interest (Decree Law no. 181/70).

Despite the simplicity of this dwelling, it is remarkable for its traditional features remained unchanged except the enlargement of the window at the ground floor and the installation of a lift in 1985 (AML, Dossier no. 33695). Another window was recently introduced on the ground floor without any municipal approval. The curved timber doorjamb is a unique example in Lisbon; the 17th century railing, *varão e nó* (*bar and node*) is also typical of this epoch. As shown by the historical photographs, the current plaster (mustard color replacing white background and darker strips in the corners) and the mentioned new openings on the ground floor are the main dissonances that should be redesigned.

Construction system

Roofing: Gabled roof

Exterior wall: Stone masonry on the ground floor; timber frame walls filled by rubble stone on the upper floors

Floor: Wooden joists and boards

Degree of structural authenticity: High
Degree of architectural authenticity: Partial
State of conservation: Mediocre

Location: *Rua do Benformoso* no. 101-103, Lisbon
Dating: before 1755
Type: Row house (one apartment for floor)
Corrent use: Mixed use
Archival Document: AML, Dossier no. 33695



Photograph by J.A.L. Bárcia (1890-1945)



Photograph by E. Portugal (1900-1958)



Photograph (2016, © S. Stellacci)

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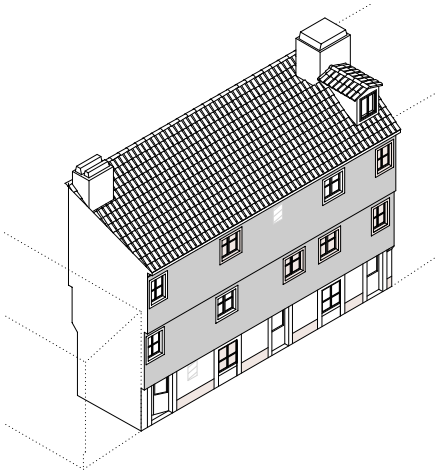
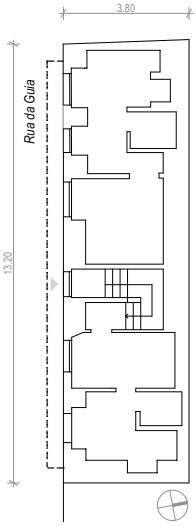
demolition new construction

Permanence and dissonances



Isometric view

original removed element
new features
new structure



Ground floor plan

Dimensional specification*
ridge height (Hc): 8.10 m
ground floor:12.20 x 3.80 m
1st floor: 12.20 x 3.73m* overhang: 0.51m
2nd floor: 12.20 x 3.97m* overhang: 0.24m
Cantilevered area:13 sqm
**average values*

Location: *Rua da Guia* no. 1-7, Lisbon
Dating: before 1755
Type: Two apartments per floor
Corrent use: Residential
Archival Document: AML, Dossier no. 34998, vols.1-2

Brief historical notes

The double jutting house dated back to the 16th century and was altered during the 17th century. Located near to a popular square, *Largo da Severa,* it is arranged on a rectangular plot. Originally conceived as a multi-family house with two apartments per floor, it is characterized by a bi-axial symmetry.
During Lisbon reconstruction aftermath of the 1755 earthquake, the same building type (so-called *right-left*) was largely employed with four main typological variants.
This layout is rare in Lisbon's medieval houses, while the common solution in the Middle Ages was characterised by an asymmetric access in the main facade. The original construction probably consisted of one floor; the upper floors with external timber-frame walls were executed during a second phase (18th century). Plumbing and sanitary facilities were also executed in this period.
The vertical continuity of the internal walls that supported the staircase suggests a strong influence of the load bearing capacity, when compared to that of the other thin walls (*tabiques*). However, the *tabiques* provided an overall interlocking of the building under seismic load, orthogonal to the main facade.
This building was altered in 1987 in absence of the municipal approval. These abusive works included the execution of concrete pilasters to support the overhangs and the replacement of timber frame walls by a concrete structure filled by hollow bricks. These works were coercively and belatedly interrupted. Lisbon Municipality was initially interested in expropriating the building and refurbishing it as a Portuguese guitar school, later, this project was discarded. The original layout of the main facade was compromised due to the alteration of openings, the loss of stone doorjambs and the introduction of heterogeneous external frames (which were guillotine windows in the 18th century). In addition, the yellow-pinked plaster represents a dissonance that needs to be resolved.



Photograph by by J. A. Goulart (1963)



Photograph (2016, ⓒ S. Stellacci)

Construction system
Roofing: Hipped
Exterior wall: Stone masonry on the ground floor and original timber frame walls with rubble stone infill on the upper floors were replaced by a concrete structure and hollow bricks.
Floor: The original wooden floors were replaced by concrete slabs.

Degree of structural authenticity: Low
Degree of architectural authenticity: Low
State of conservation: Good

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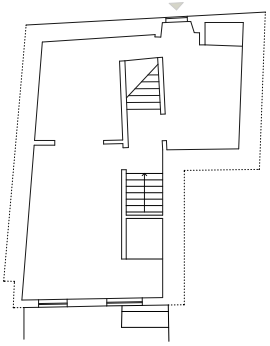
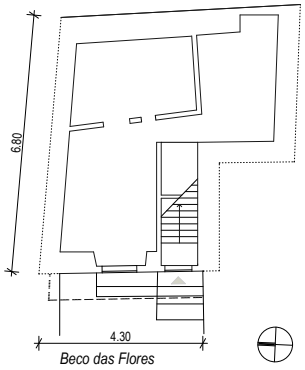




Ground floor - 1st floor plans

Dimensional specifications*
ridge height (Hc): 8.20 m
gross floor area: ground floor: 39 sqm, 1st/2nd floor: 42. 40 sqm
overhangs: 0.70m x 4.10 m
Cantilevered area: 5.80 sqm
**average values*

Location: *Beco das Flores* no. 23-25, Lisbon
Dating: before 1755
Type: One apartment for floor, double access
Corrent use: Residential (abandoned)
Archival Document: AML, Dossier no. 8956

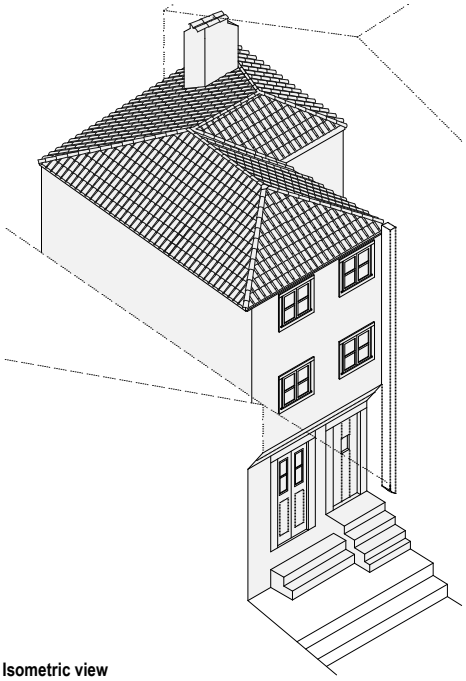


Brief historical notes
Arranged on L-shaped plan, this small house has a double access, one in *Beco das Flores* and the second higher at the easter side. The western two-story facade on the upper floors, enclosed between two orthogonal buildings plots, is made of timber frame structure, while the other facade is a stone wall, whose typical roofing is the double eaves closure (*beirado à portuguesa*).
Typical features of Portuguese urban house and rural house are merged into this dwelling. The overhang facade (70cm in width) is supported by both floor joists and gables neighbors. The vertical connection of the internal compartment is made through a typical straight flight stair, leaning on the gable wall and on the timber frame wall (12cm of thickness), whose irregular carpentry joints constitute the weak points of this construction. In addition, the ridges beams, the rafters, and the ceiling joists are very vulnerable because these members are just nailed. The existing roof probably has been replaced.
Timber planks protect the overhang (with a typical *saia e camisa* layout), which was maintained until nowadays, while archival photographs shows the chromatic difference between the whole facade and its corners, which was replaced by a monochrome plaster. Severe pathologies affecting the external surface, timber planks, and stoneworks should be solved through adequate repairs. Some technical reports included into the dossier of AML (no. 8956) refer to the necessity of these works since in 1927 and in 1989, and are still valid.



Archival photograph by E. Portugal (1900-1958)

Permanence and Dissonances



Isometric view

original architectural/structural features

Construction system
Roofing: Hipped
Exterior wall: Limestone masonry on the ground floor and timber frame walls filled by rubble stone on the upper floors overhanging *Beco das Flores*
Floor: Timber floors and boards

Degree of structural authenticity: High
Degree of architectural authenticity: High
State of conservation: Mediocre



Photograph (2017, ⓒ S. Stellacci)

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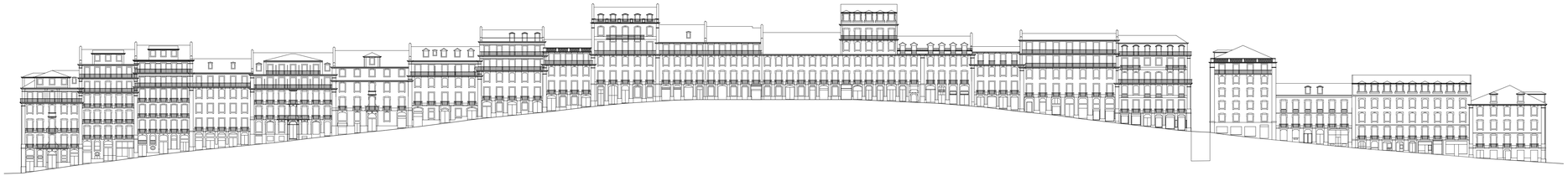
APPENDIX C

C.1.1 Location of case study 1 and main elevations



nos. 83 - 87 | nos. 89 - 93 | nos. 95 - 99 | nos. 101-109 | nos. 111-115A | nos. 117-121 | nos. 123 -127 | nos. 129 -137 | nos. 139 -145 | nos. 147-155 | nos. 157-163 | nos. 165 - 173 | nos. 175 - 187 | nos. 189 - 197 | nos. 199 - 209 | nos. 211 - 217 | nos. 219 - 231 | nos. 233 - 243 | nos. 245 - 251 | nos. 253 - 263 | nos. 265 - 279 | nos. 283 - 291

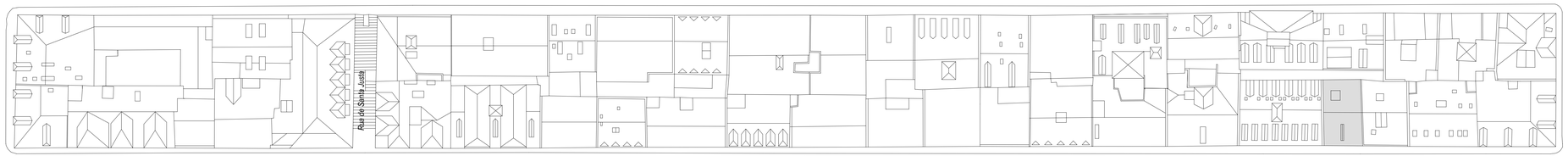
Rua da Madalena

Rua da Madalena



no. 5 | nos.1-3A

Rua de Santa Justa



Rua dos Fanqueiros

Rua da Conceição



nos. 10 -18 | nos. 2- 8

Rua da Conceição

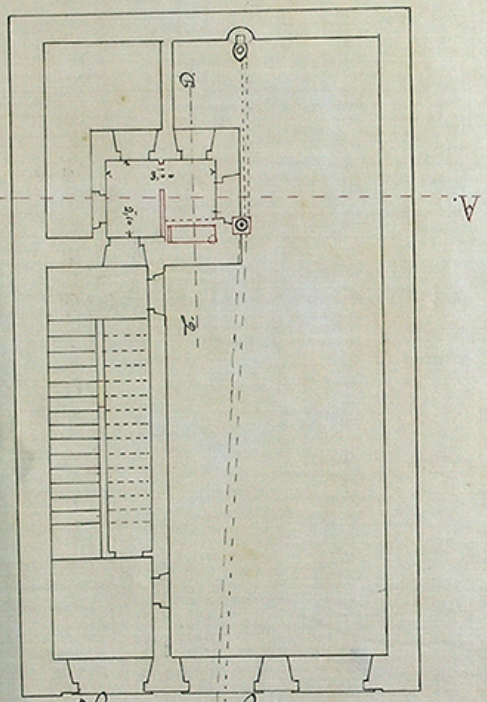


nos. 314 - 320 | nos. 306 - 312 | nos. 294 - 304 | nos.288 - 292 | nos. 280 - 286 | nos. 270 - 278 | no.258-268 | nos. 244 - 256 | nos. 234 - 242 | nos. 226 - 232 | nos. 212 - 224 | nos. 202 - 210 | nos. 190 - 200 | nos. 180 - 188 | nos. 170 - 178 | nos. 162 - 168 | nos. 152 - 160 | nos. 142 -150 | nos. 132 -140 | nos. 116 -130 | **nos.110 - 114** | nos.102 -108 | nos. 90 -100 | nos. 78 - 88

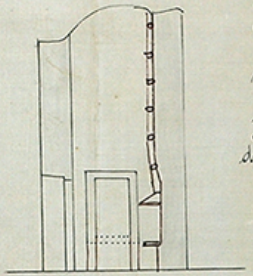
Rua dos Fanqueiros

0 20.00 m

Folhas 2
Proc.º Pol.ª N.º 514 /11



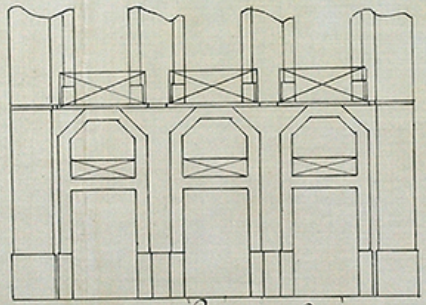
Planta da Loja



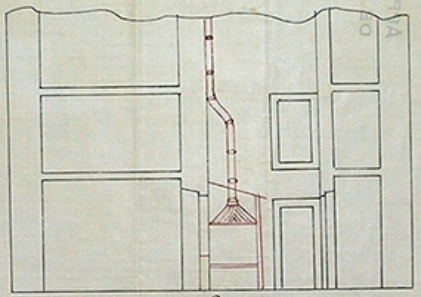
Corte por C. D.

Projecto para uma chaminé de ferro provisoria, e divisão com cobertura de vidro que o Snr Joaquim Rodrigues Rosa pretende fazer no saguão da sua loja situada na Rua dos Tanqueiros N.os 110 a 114, freguezia de Santa Justa 2.º Bairro





Alçado da frente



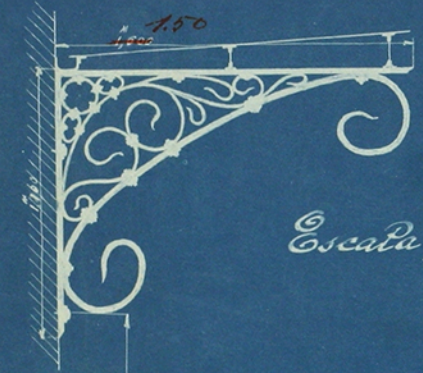
Corte por A. B.

APPENDIX C

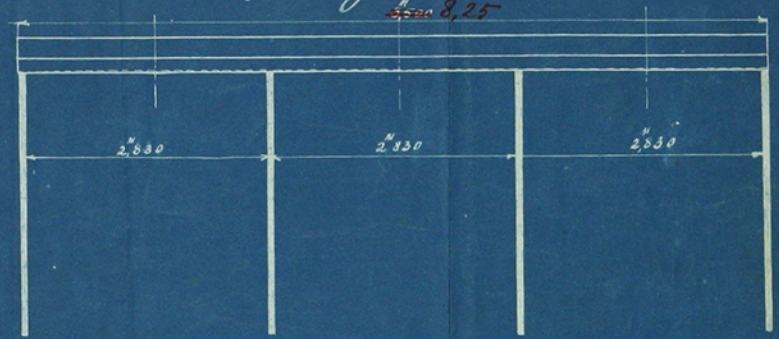
Folhas 2

Proc.º N.º 3826/10

Projecto de marquise que o Sñr. Eugenio Pires L.da deseja mandar colocar na fachada do seu estabelecimento da Rua dos Fanqueiros N.os 110-112-114 1/2 - Freguezia de S. Nicolau - 2.º Bairo



Escala 1/20

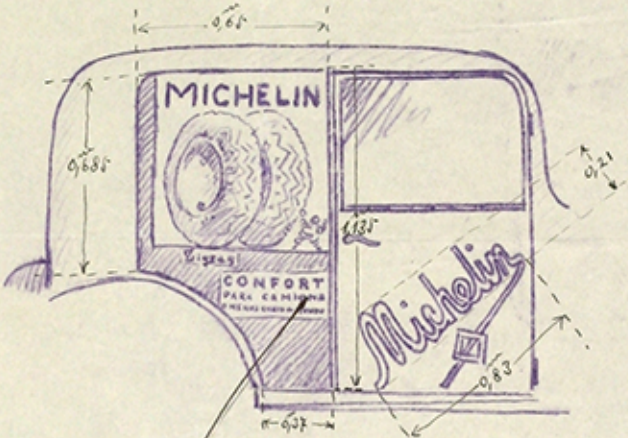




C.1 Case study 1

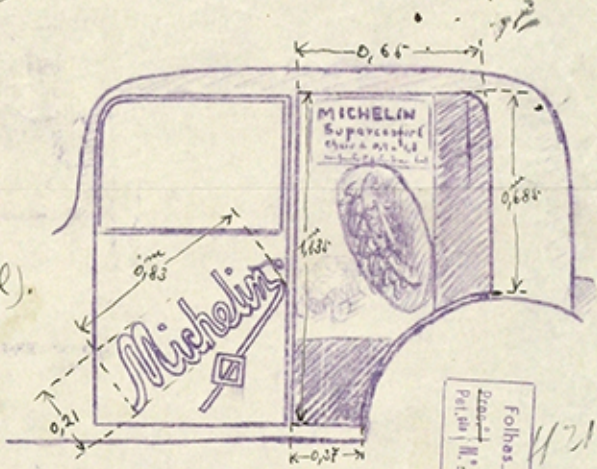
Retaguarda do automovel.





Lado direito do carro (automóvel).

Camião
21-8-934



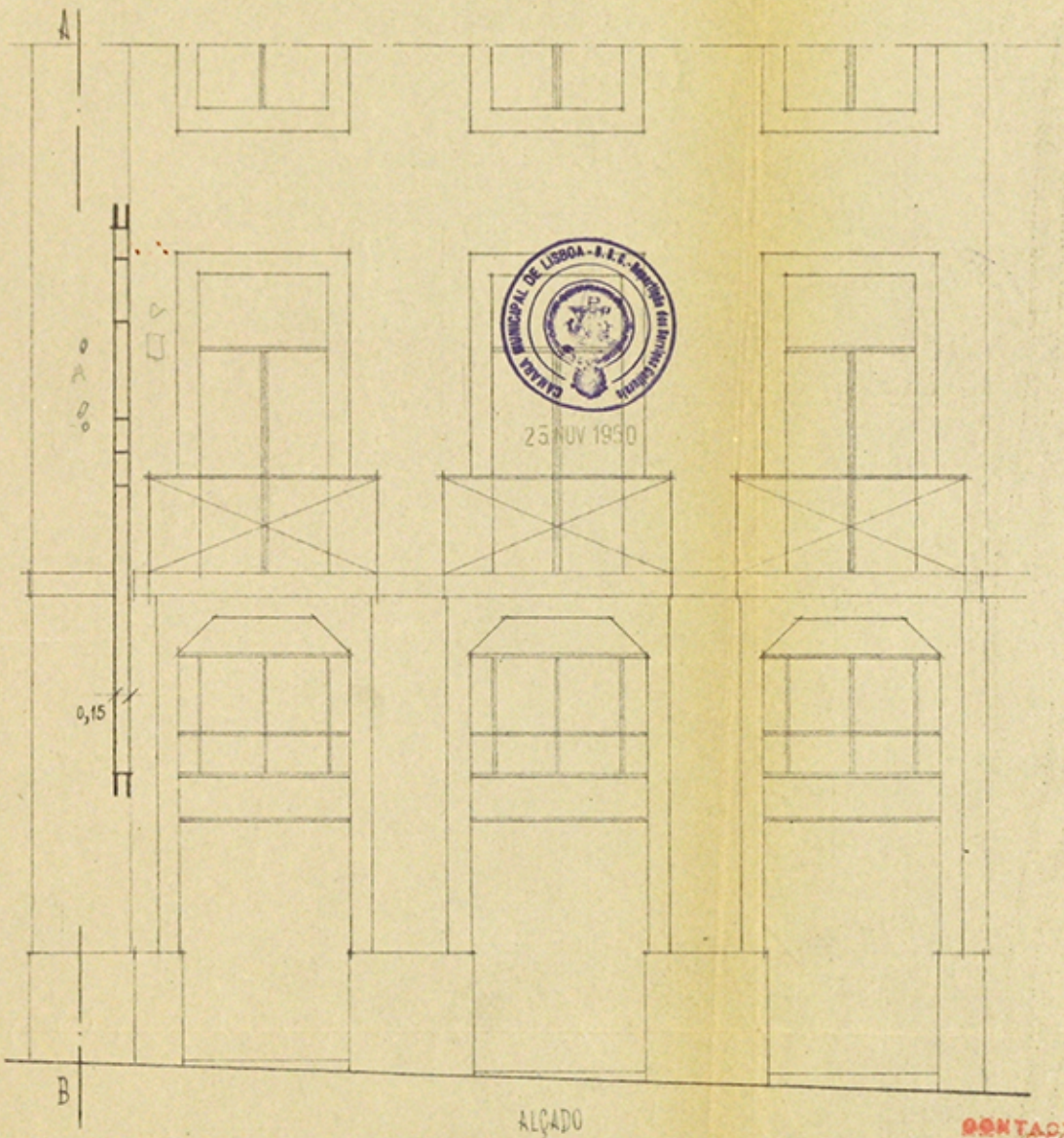
Lado esquerdo do carro (automovel).



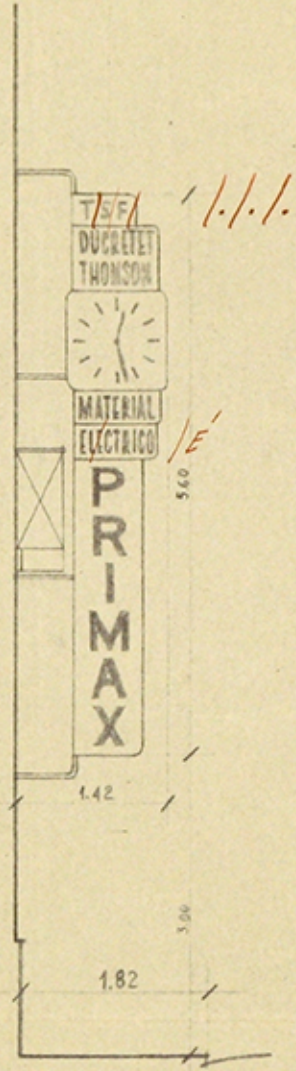
Lisboa, 16 Agosto 1934.
Antonio Martins Jacinto Nunes.

Folhas 2
Proc.º
Pet. Gar. N.º 4213/34

C.1.2 Archival documents (AML, PO 38639)



ALÇADO



CÓRTE "A-B"

CONTACTO, Lda.
5$00
PORTUGAL
GERENTE
1/11/552

Contacto, L.da

1/50

PROJECTO PARA O MELHORAMENTO DAS SUAS INSTALAÇÕES QUE A FIRMA "PRIMAX" LDA" PRETENDE LEVAR A EFEITO NA RUA DOS FANQUEIROS Nº 114 1º

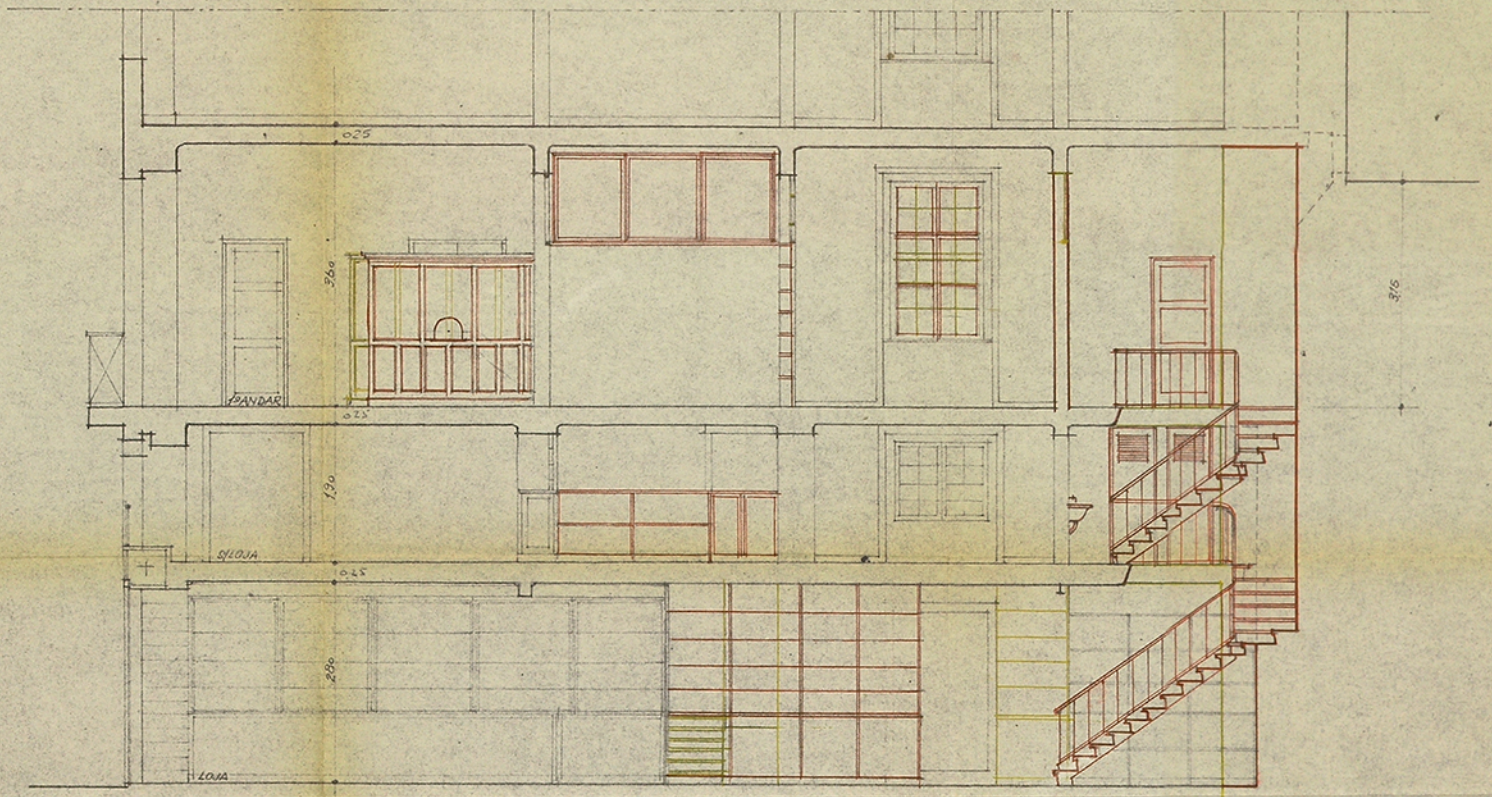
ESCALA 1:50

G.ª 6 P.º 16 D.º 2
Des. A.C.A. em 25/9/50
Cop. » / /
Ver. » / /
Alt. » / /
» » / /
» » / /
Visto

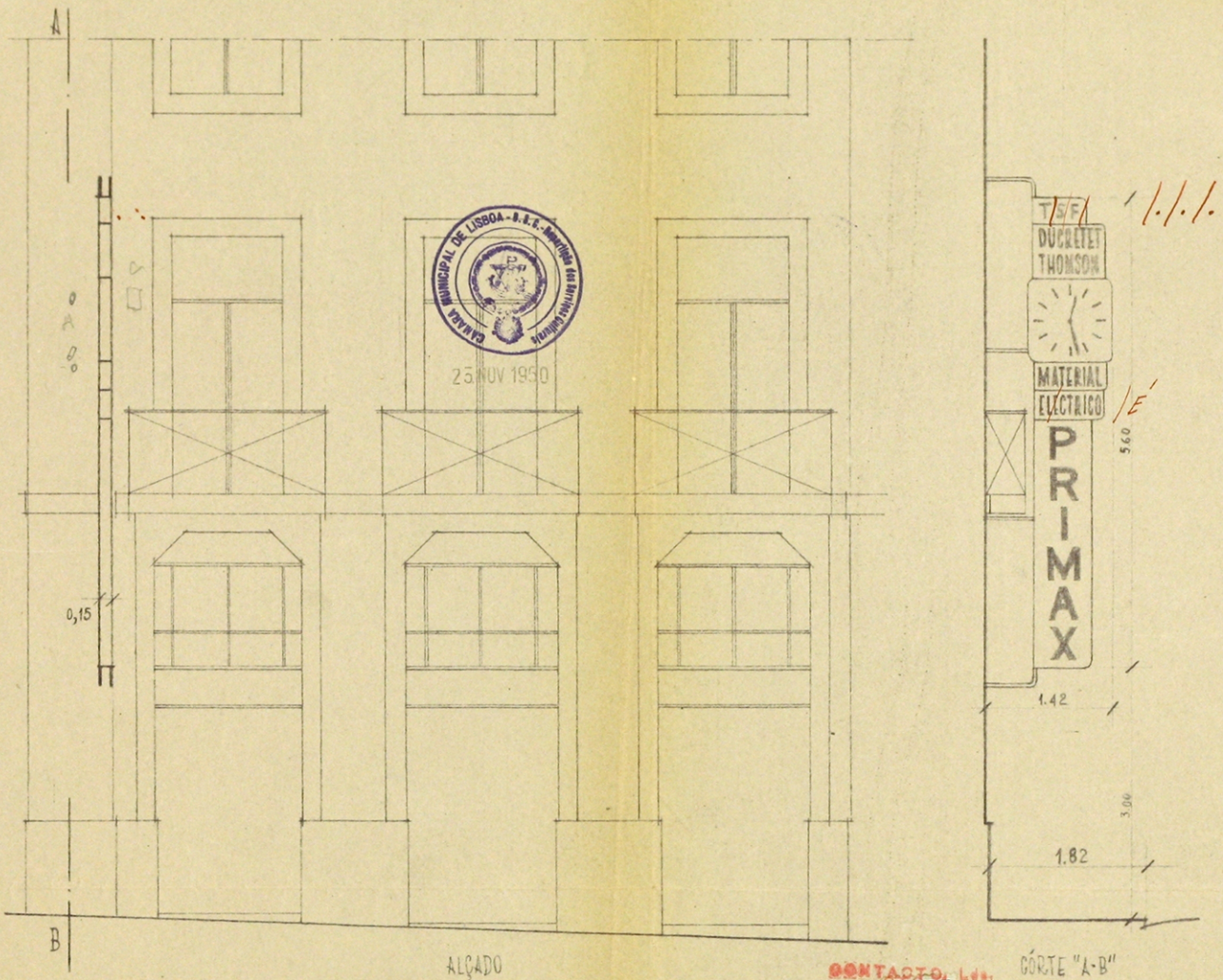
5$00 PORTUGAL

VISTO
DA REPARTIÇÃO [Arquitectura]
O ARQUITECTO

Folha 4
Proc.º 41340/950



CORTE POR A:B



ALÇADO

CÓRTE "A-B"

CONTACTO, Lda.

5$00 PORTUGAL CINCO ESCUDOS

GERENTE

11/552

Contacto, Lda

1/50

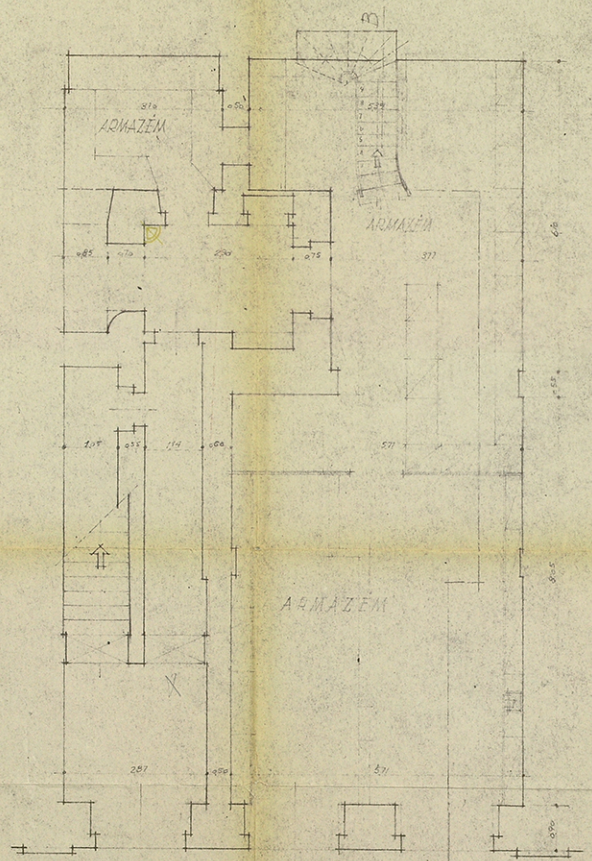
PROJECTO PARA O MELHORAMENTO DAS SUAS INSTALAÇÕES QUE A FIRMA "PRIMAX LDA" PRETENDE LEVAR A EFEITO NA RUA DOS FANQUEIROS Nº 114-12

ALTERAÇÃO AO PROC.º Nº 41340/50

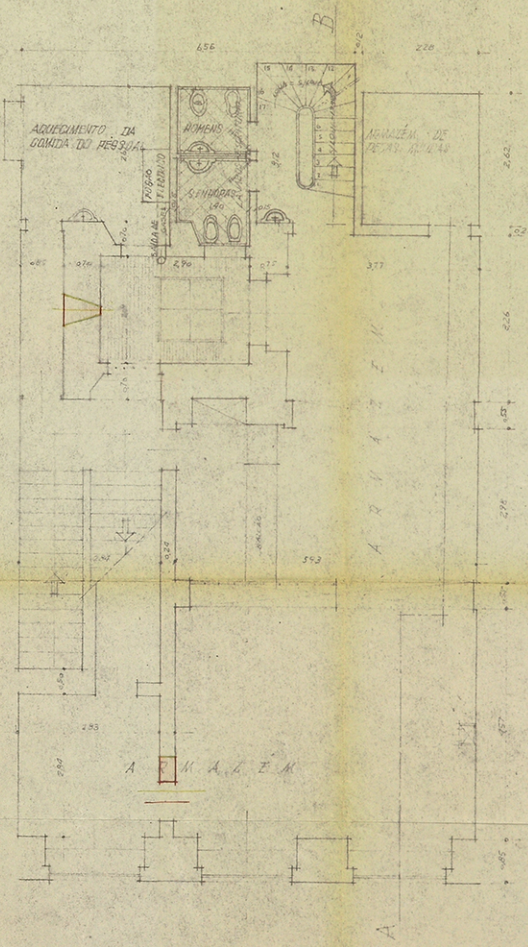
Folha 3
Proc.º 9352/951

5$00 VIRTUAL

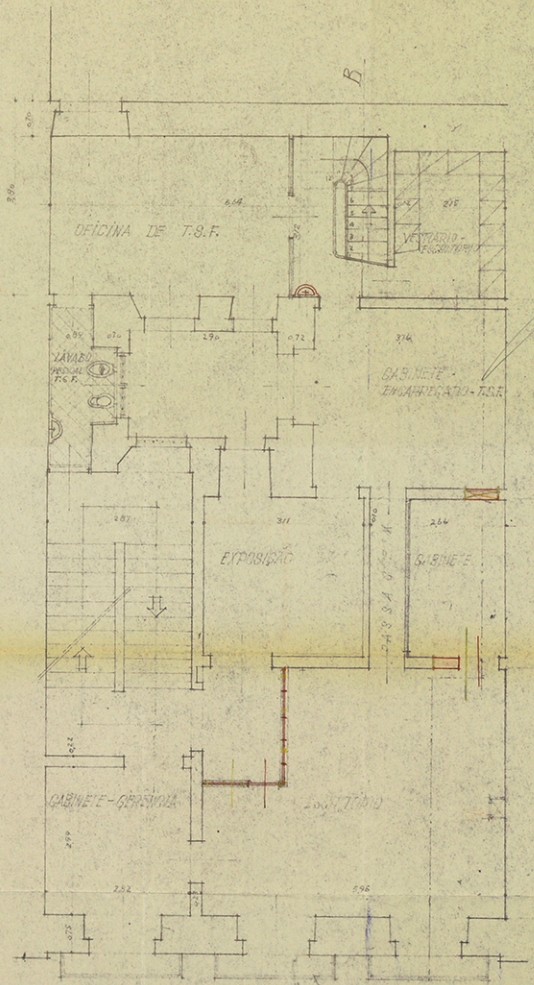
VISTO
DEPARTAÇÃO (Arquitectura)
e ARQUITECTO



PLANTA DA LOJA



PLANTA DA SILOJA



PLANTA DO RANDAR

ESCALA 1:50

O ARQUITECTO
INSCRITO Nº 43
JOÃO SIMÕES

PROJECTO PARA O MELHORAMENTO DAS SUAS INSTALAÇÕES QUE A FIRMA "PRIMAX" LDA PRETENDE LEVAR A EFEITO NA RUA DOS BANQUEIROS Nº 114 1º

ESCALA 1:50

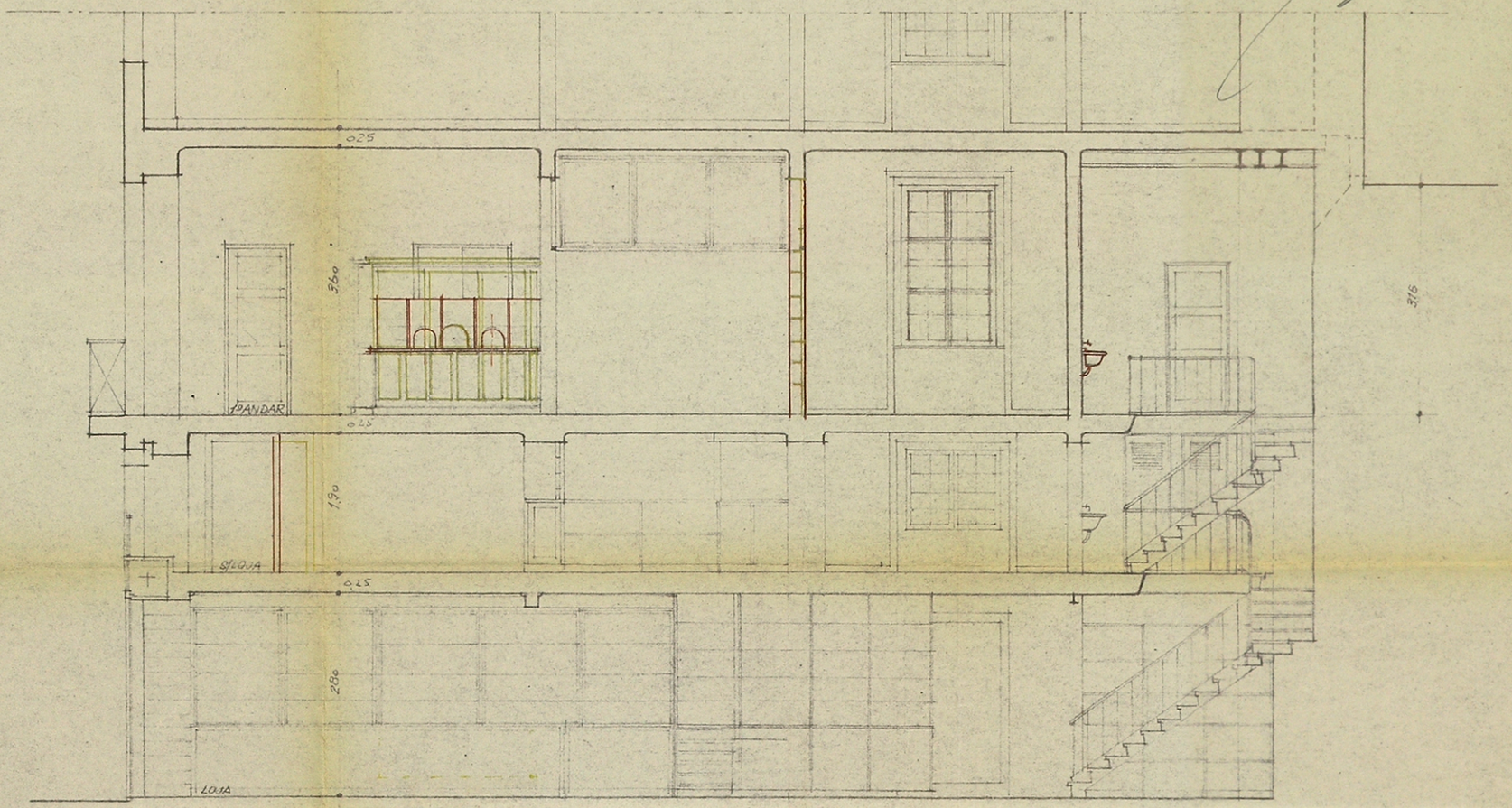
ALTERAÇÃO AO PROCº Nº 41340/50

G. P. 16 D. 2
Des. A.C.A. em 25 / 9 / 50
Cop.
Ver.
Alt.
Visto

Folha 4
Proc.º 9352/951

5$00 PORTUGAL SELO MOVEL CINCO ESCUDOS

VISTO
REPARTIÇÃO (Arquitectura)
O ARQUITECTO



CORTE POR A:B

O ARQUITECTO
INSCRITO Nº 48
JOÃO SIMÕES

PRIMAX, LDA

RUA DOS FANQUEIROS, Nº 114, R/C, S/L, 1º E 2ºA

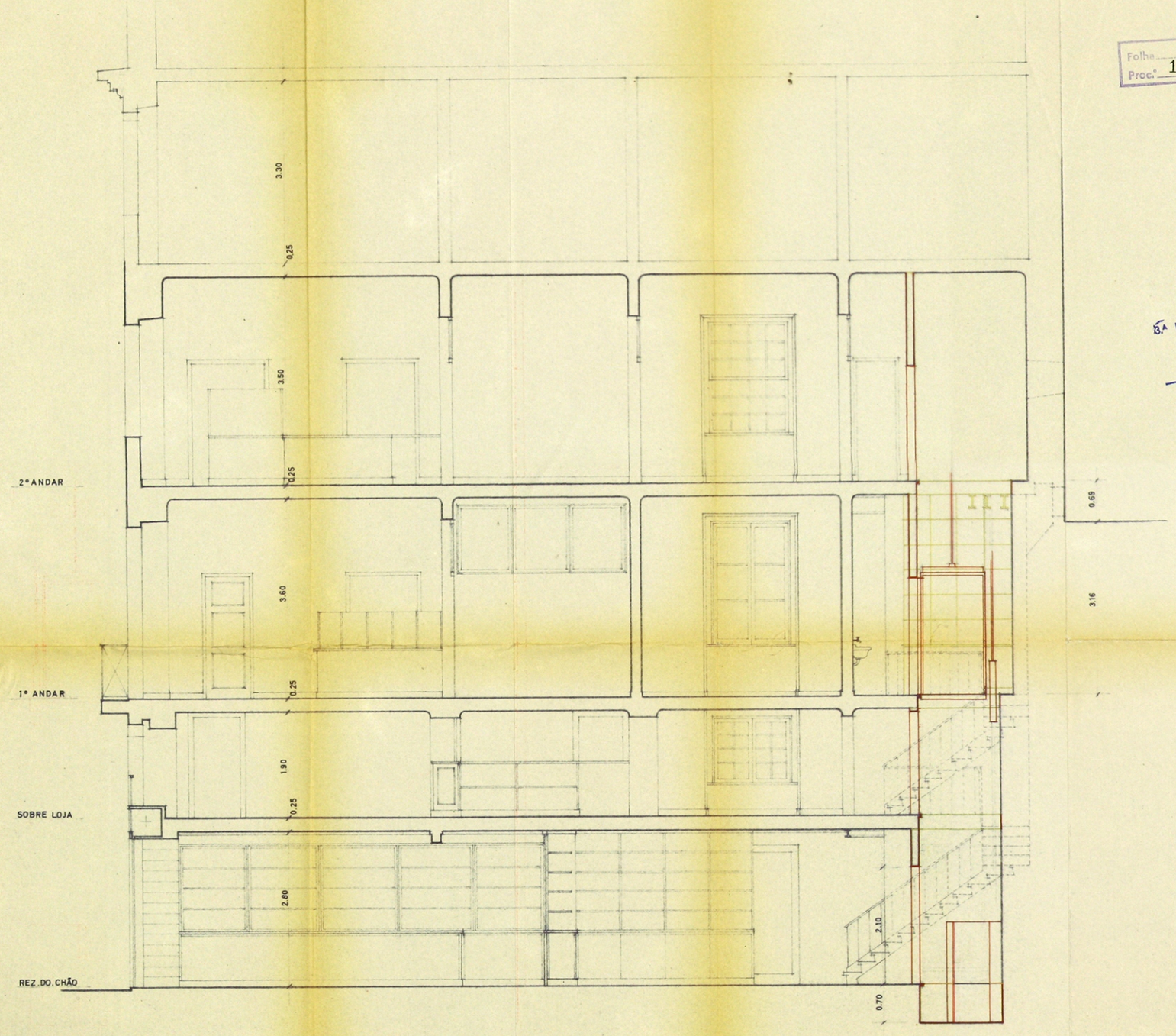
PROJECTO PARA INSTALAÇÃO DE MONTA-CARGAS ENTRE O REZ.DO.CHÃO E O 2º ANDAR

escala 1:50

Folha 5
Proc.º 17306/961

5$00 PORTUGAL CINCO CEGODOS

3.ª REPARTIÇÃO — ARQUITECTURA
VISTO
O ARQUITECTO



corte A.B.

O ENGENHEIRO

DESENHO Nº 61/80.SD

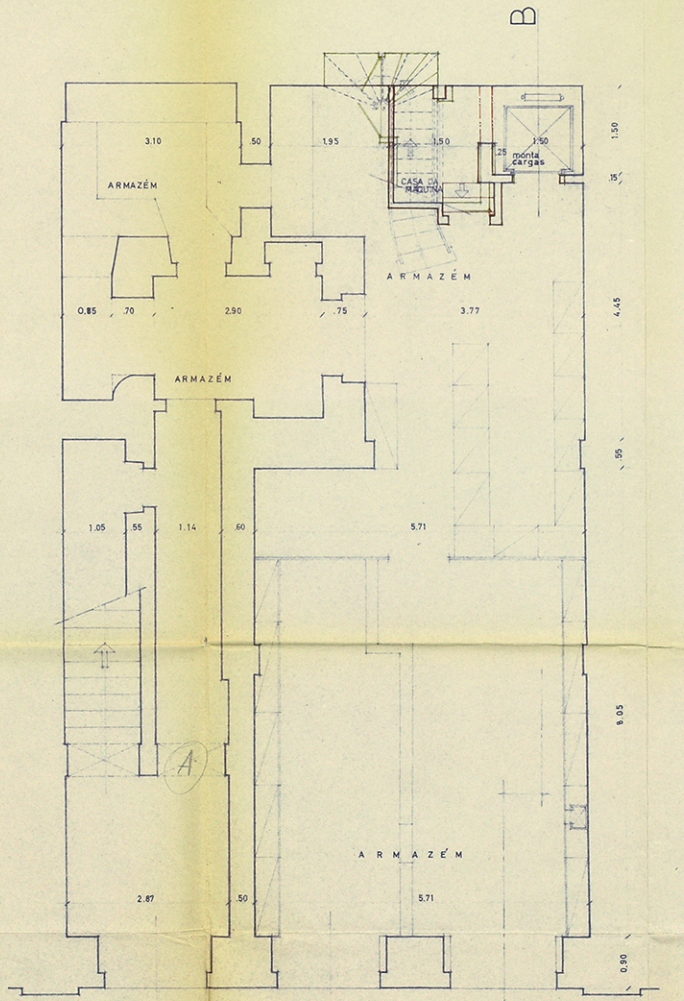
PRIMAX, LDA

RUA DOS FANQUEIROS, Nº 114, R/C, S/L, 1º E 2º AND.

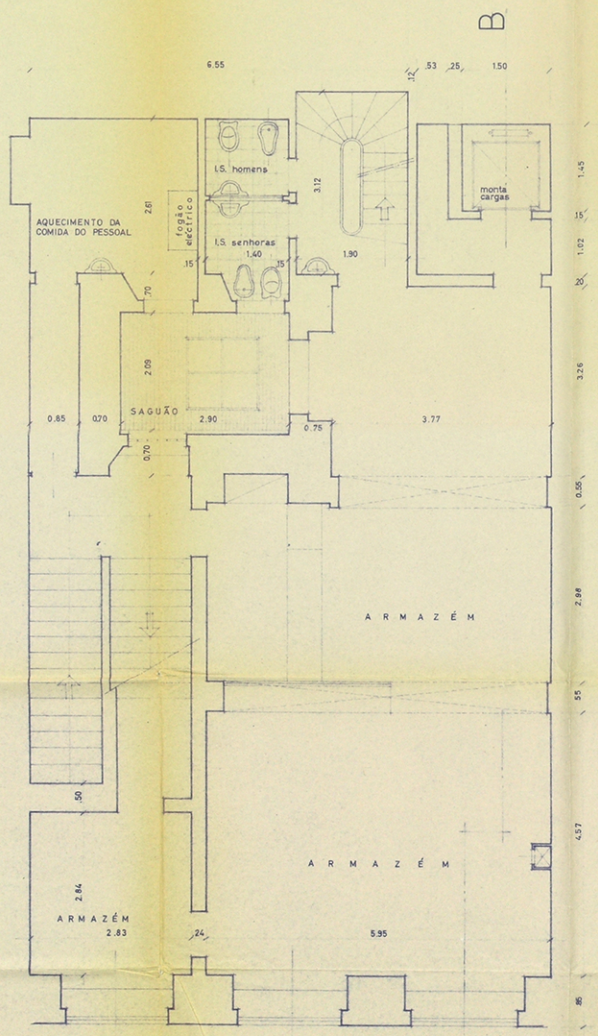
ALTERAÇÕES AO

PROJECTO PARA INSTALAÇÃO DE MONTA-CARGAS ENTRE O REZ.DO.CHÃO E O 2º ANDAR

escala 1:50



planta do r/c



planta da s/loja

5600 PORTUGAL
Folha 3
Proc.º 12450 962
3.ª REPARTIÇÃO — ARQUITECTURA
VISTO
O ARQUITECTO

O ENGENHEIRO

Manuel Sen Rey

Eng.º nº 0435

PRIMAX, LDA.

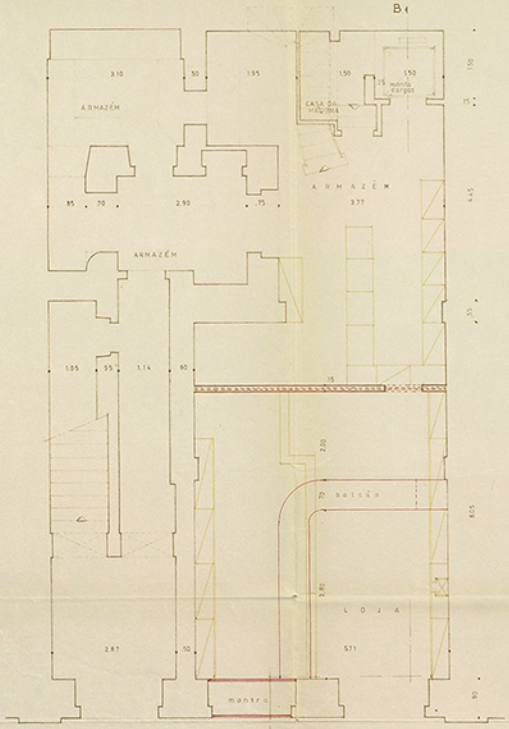
RUA DOS FANQUEIROS, Nº 116

PROJECTO DE MODIFICAÇÃO

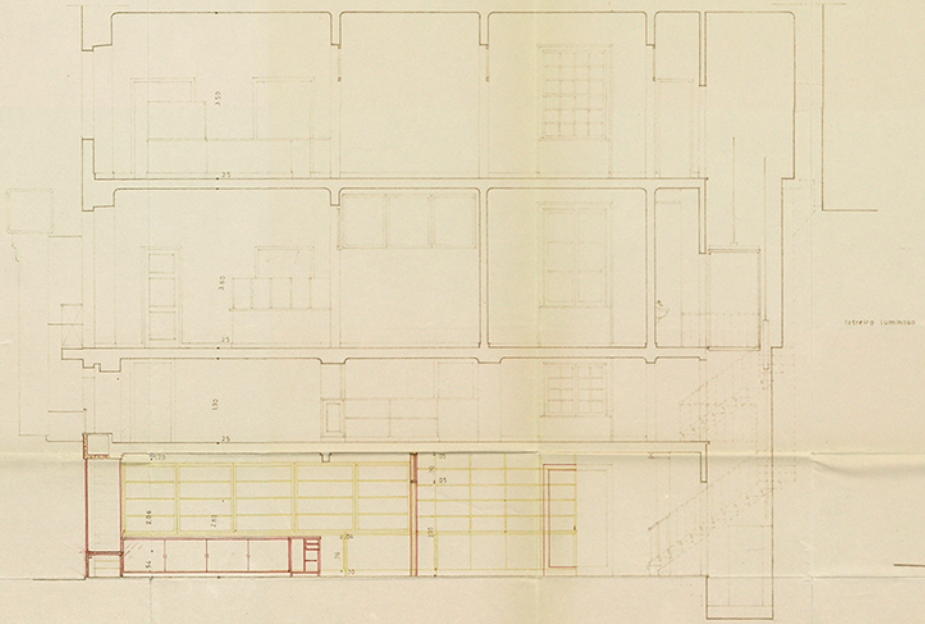
escala 1:50

Folha 3
Proc 50092/965

3ª REPARTIÇÃO – ARQUITECTURA
VISTO



PLANTA



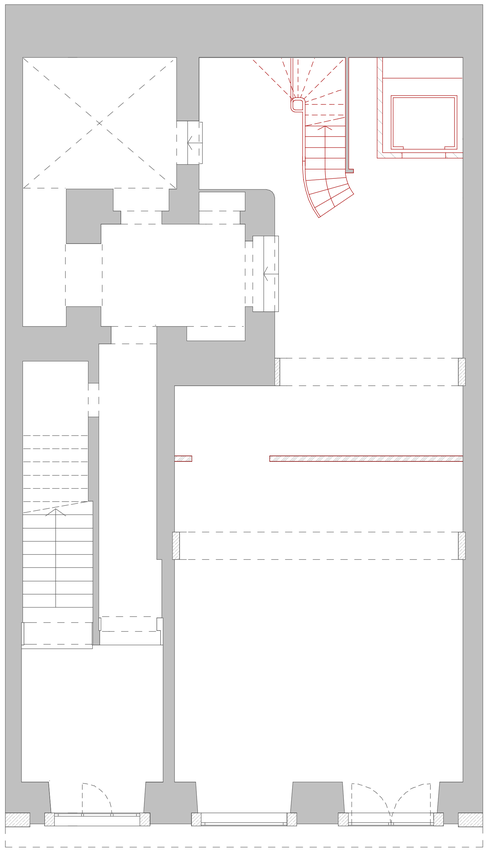
CORTE POR A-B



ALÇADO PRINCIPAL

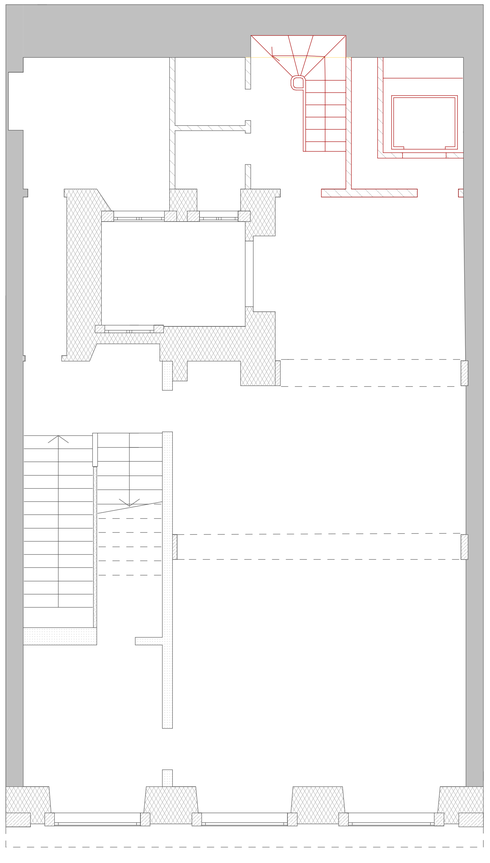
O ENGENHEIRO Nº 887

C.1.3 Technical Drawings

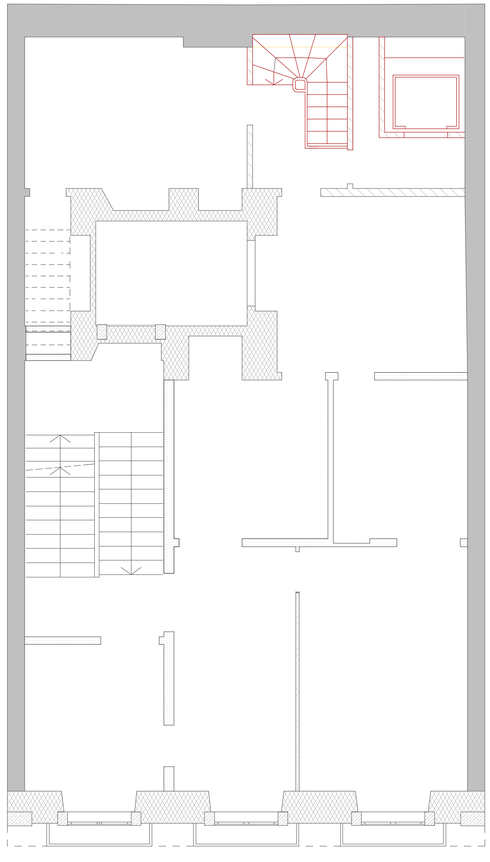


Ground floor

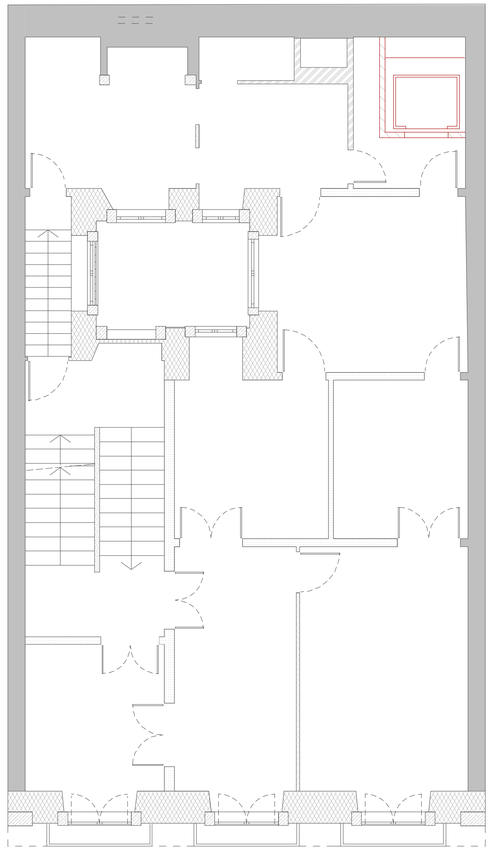
9.73



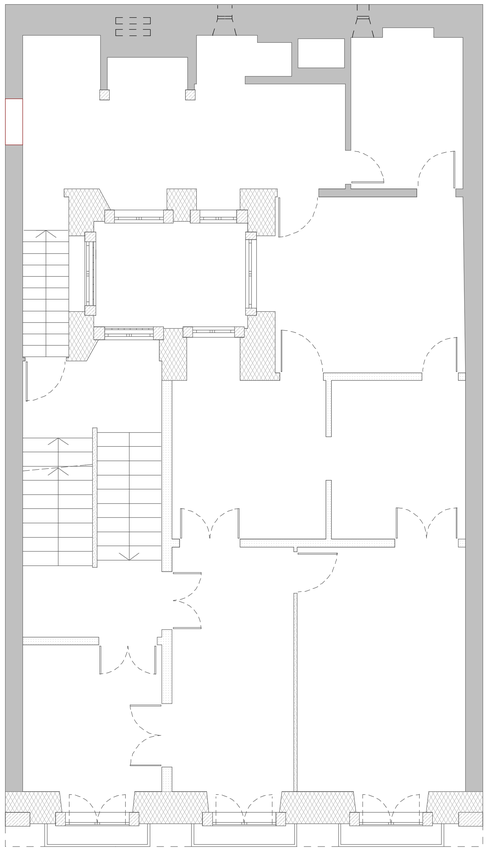
Mezzanine



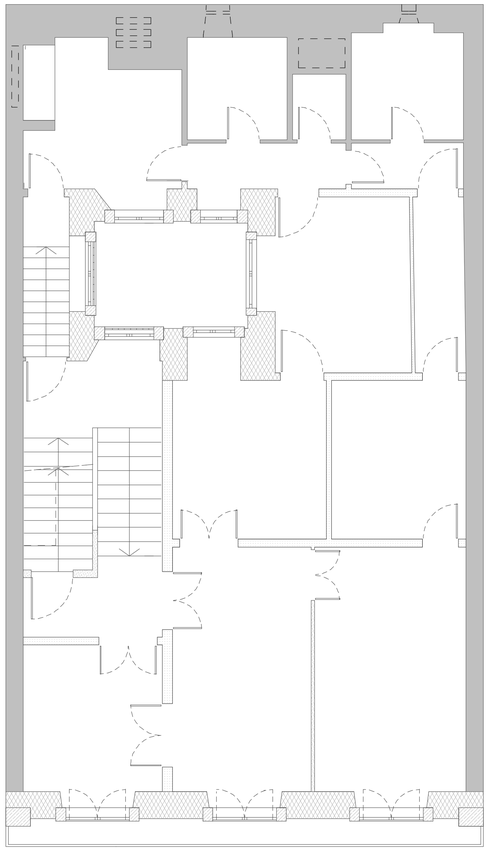
1st floor



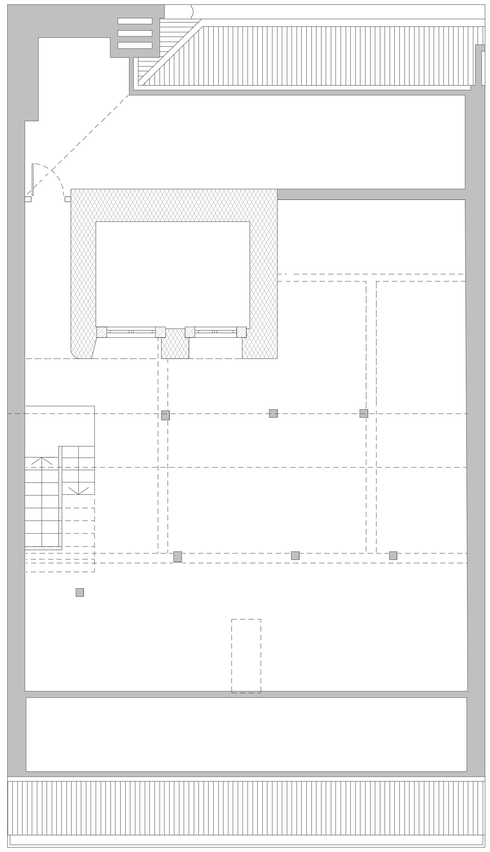
2nd floor



3rd floor



4th floor



5th floor

N

0 1m 2m

demolition (2nd phase)

construction (2nd phase)

rubble stone masonry wall

limestone wall

masonry wall reinforced by wood

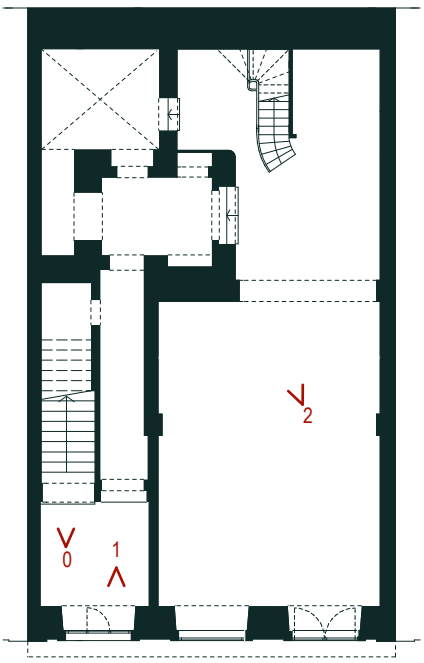
timber frame wall (TFW)

tabique wall

concrete wall

hollow brick wall

C.1.4 Photographs



N

GROUND FLOOR



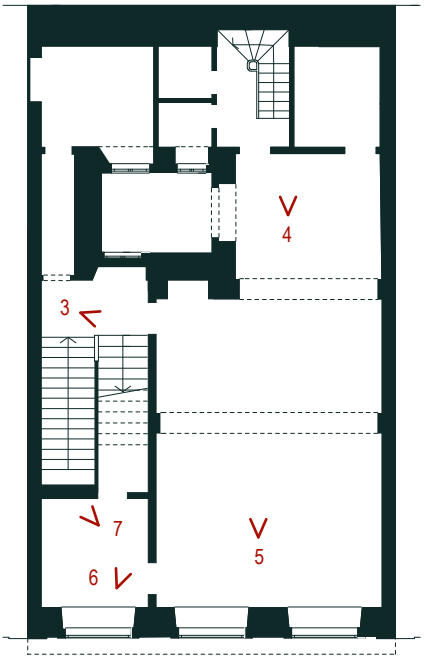
0



1



2



MEZZANINE



3



4



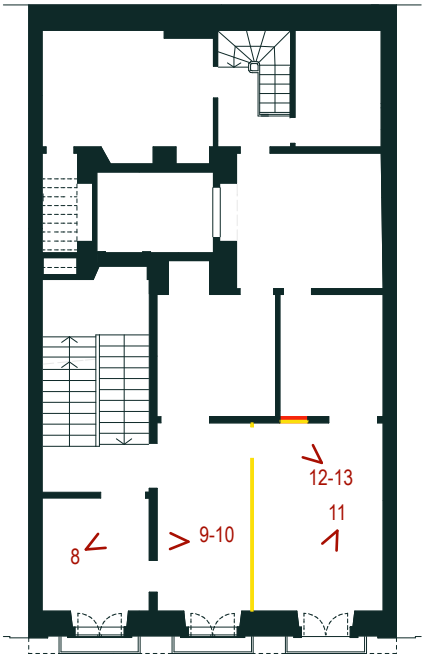
6



5



7



1st FLOOR



8



9



10



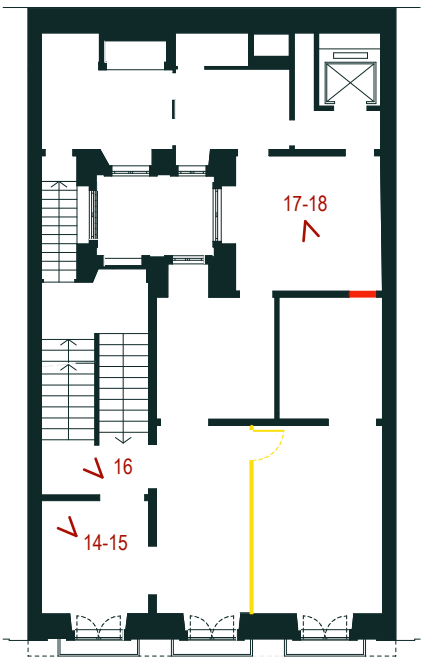
11



12



13



2nd FLOOR



14


15

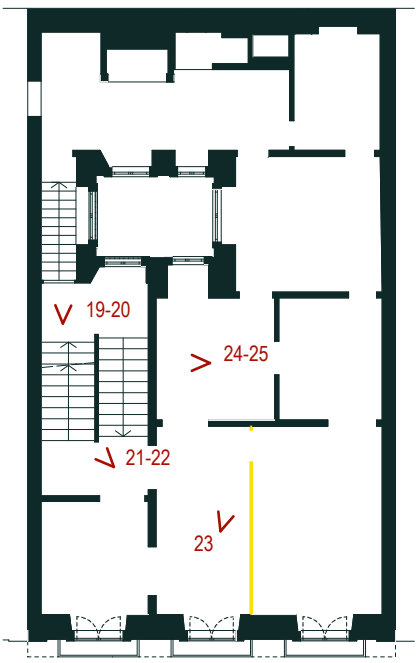

16



17



18



3rd FLOOR



19



20



21



22



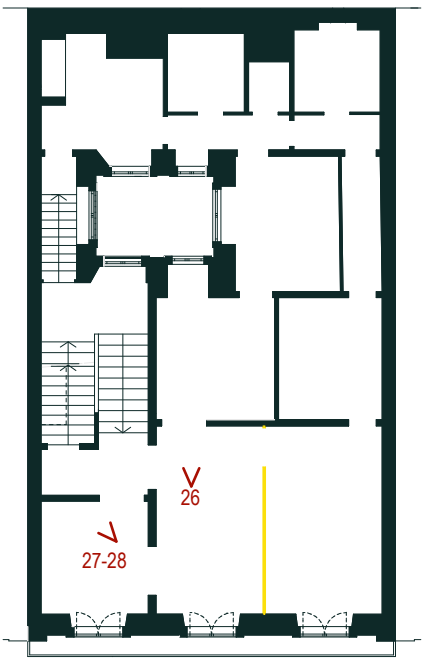
23



24



25



4th FLOOR



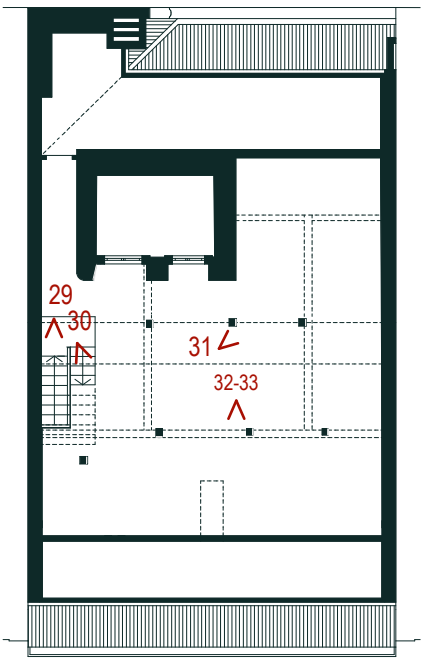
26



27



28



ATTIC



29



30



31

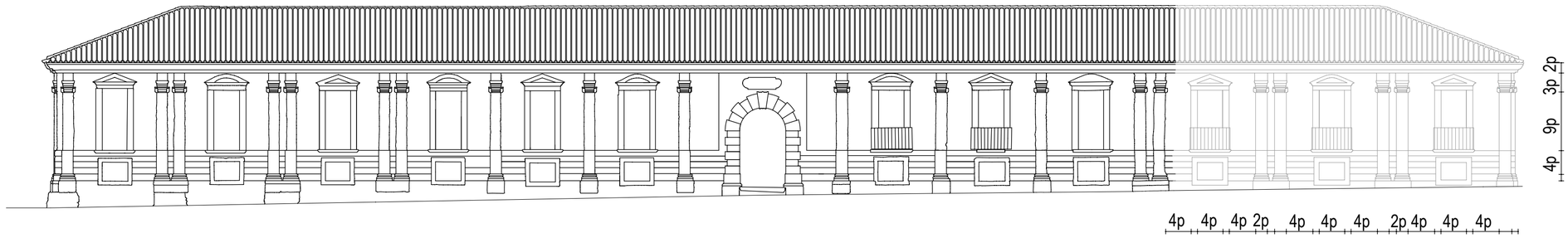


32



33

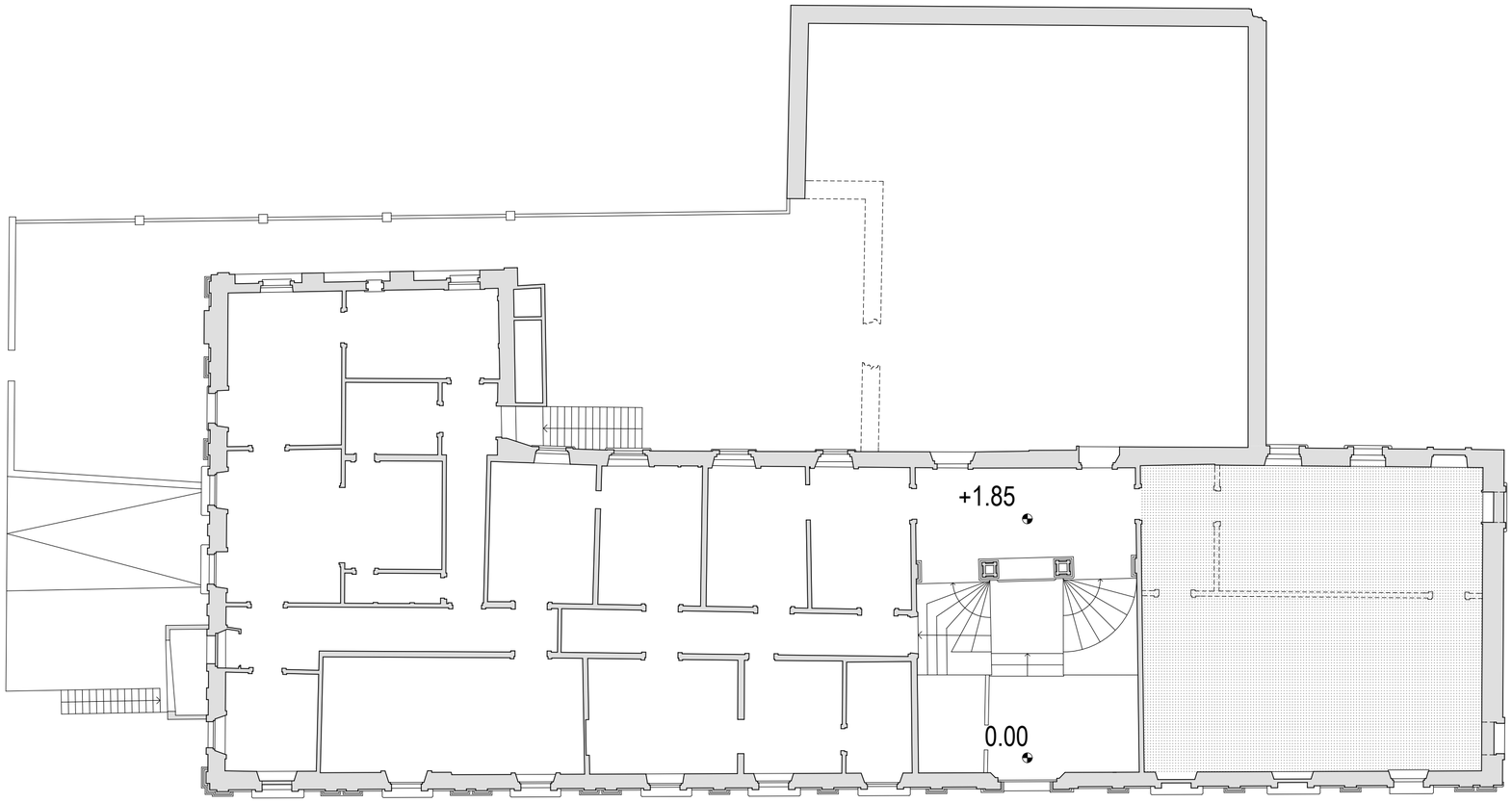
C.2.1 Technical Drawings



North Elevation

current state

configuration hypothesis



1st floor plan

N

0 2m 5m



ideal "double square"

axis of symmetry

realized area

unrealized area

Bishop's Palace location

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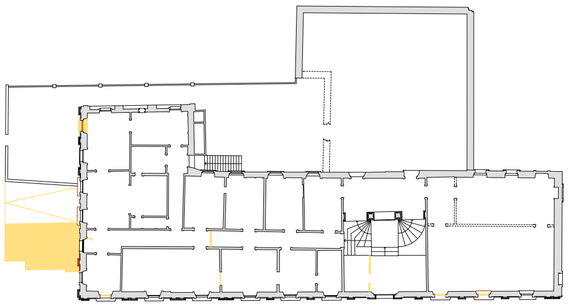

demolition

new construction

+1.85

0.00

not surveyed

1st floor plan

N

0 2 m

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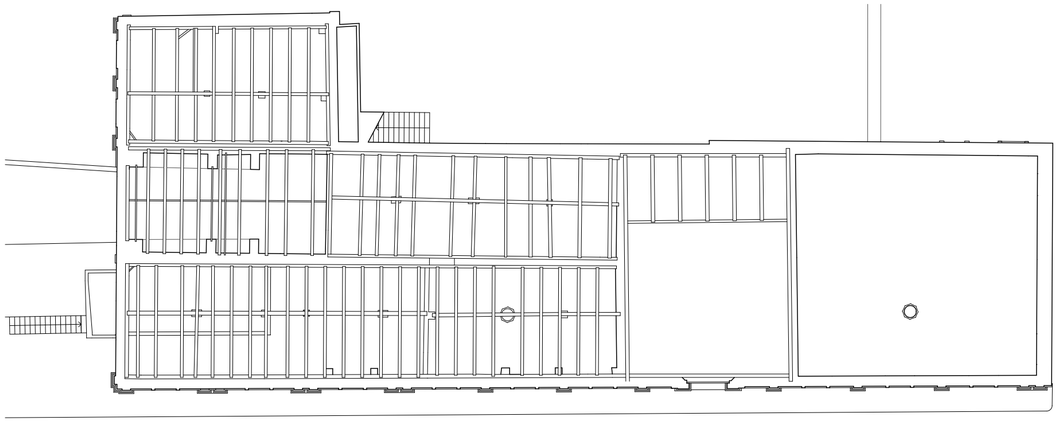

floor structure

N

ground floor plan (- 0.70)

0 2 m

(based on drawing by Prof. Andrea Lonetti)

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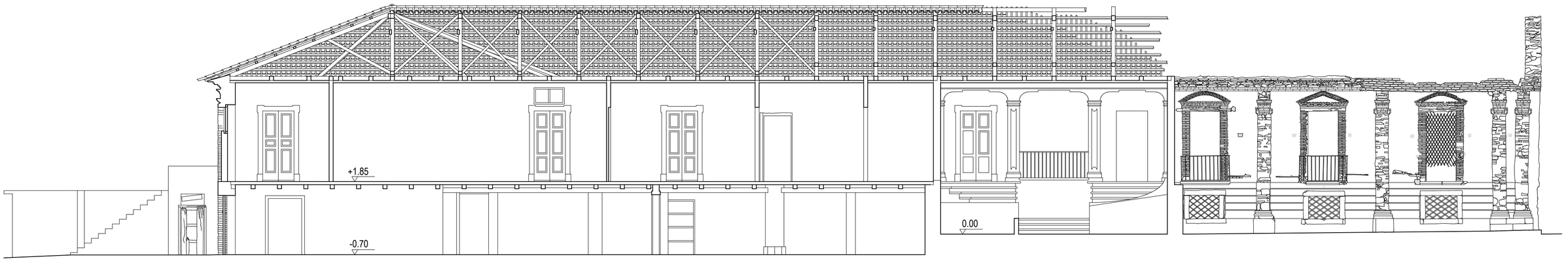
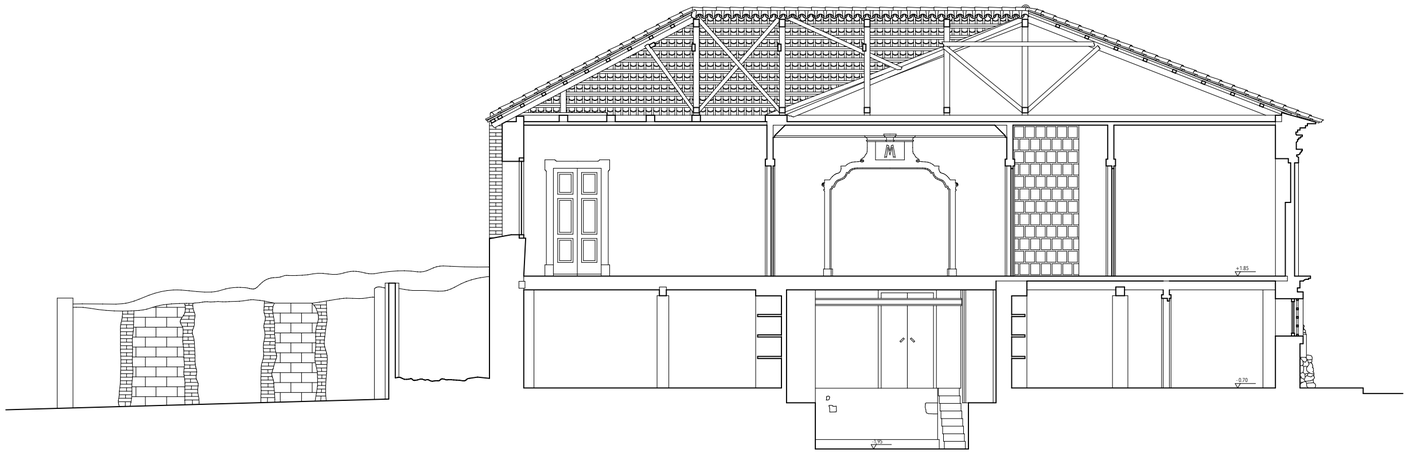
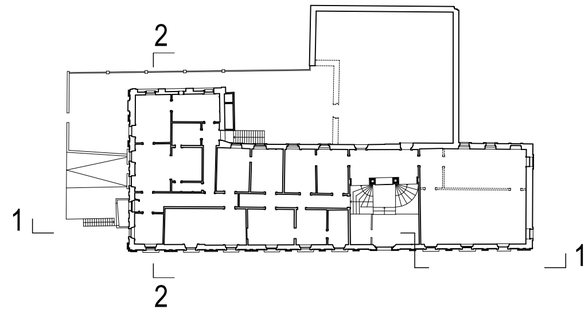
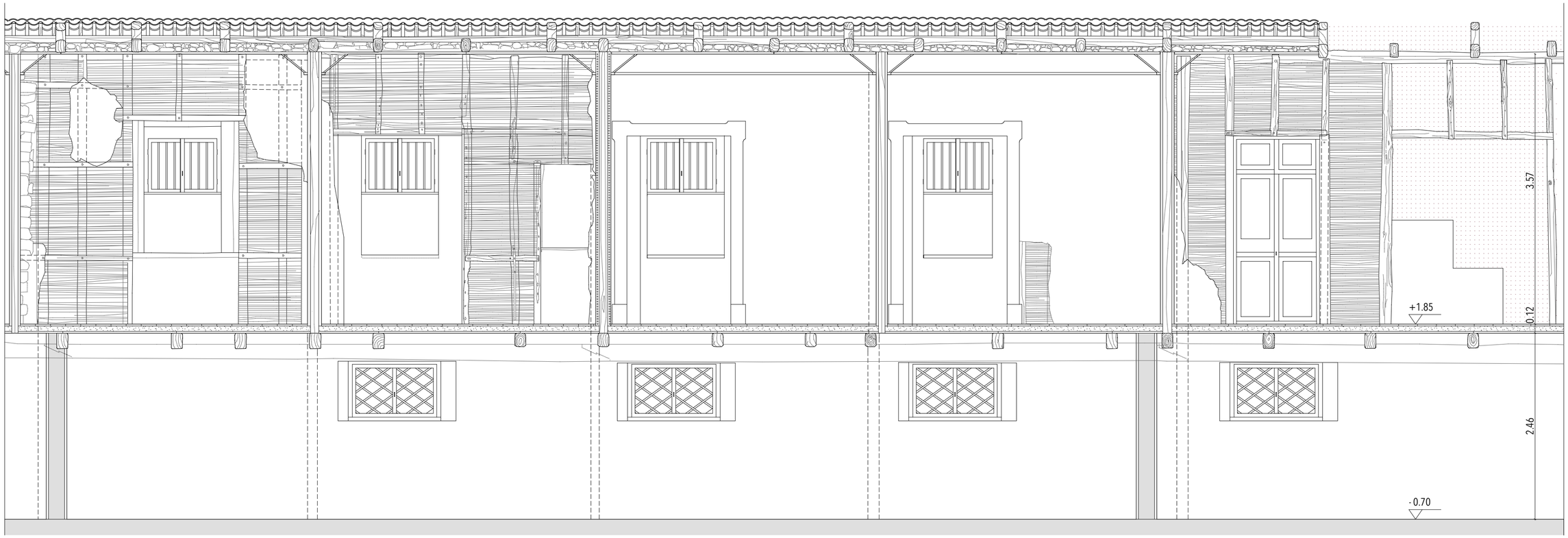


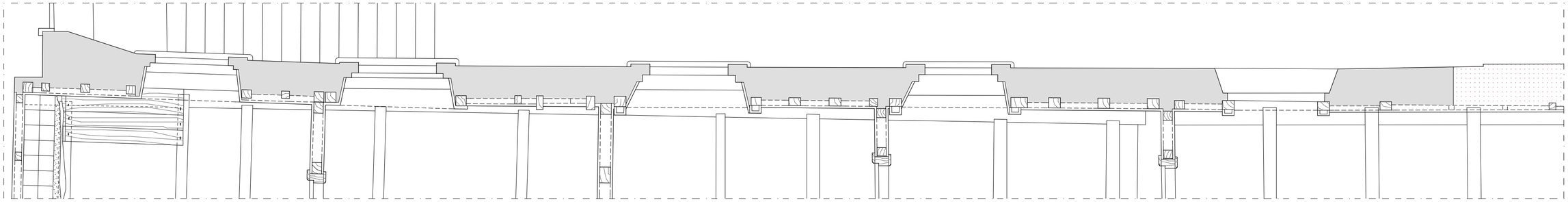
1



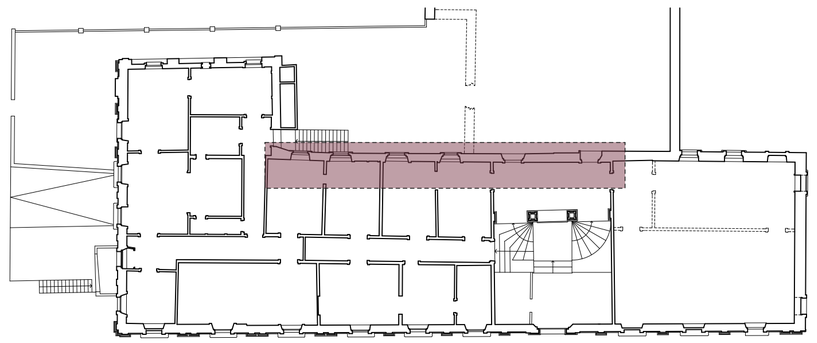


(© Prof. Andrea Lonetti)





demolished 0 1m



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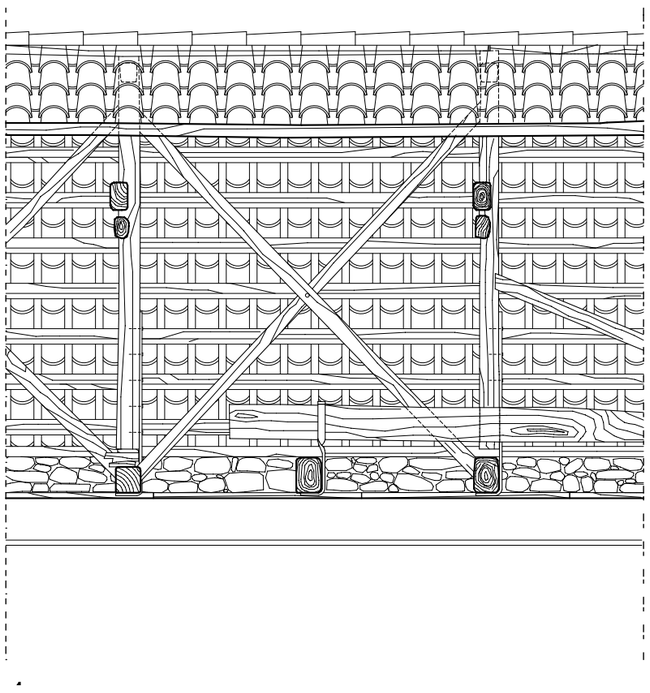
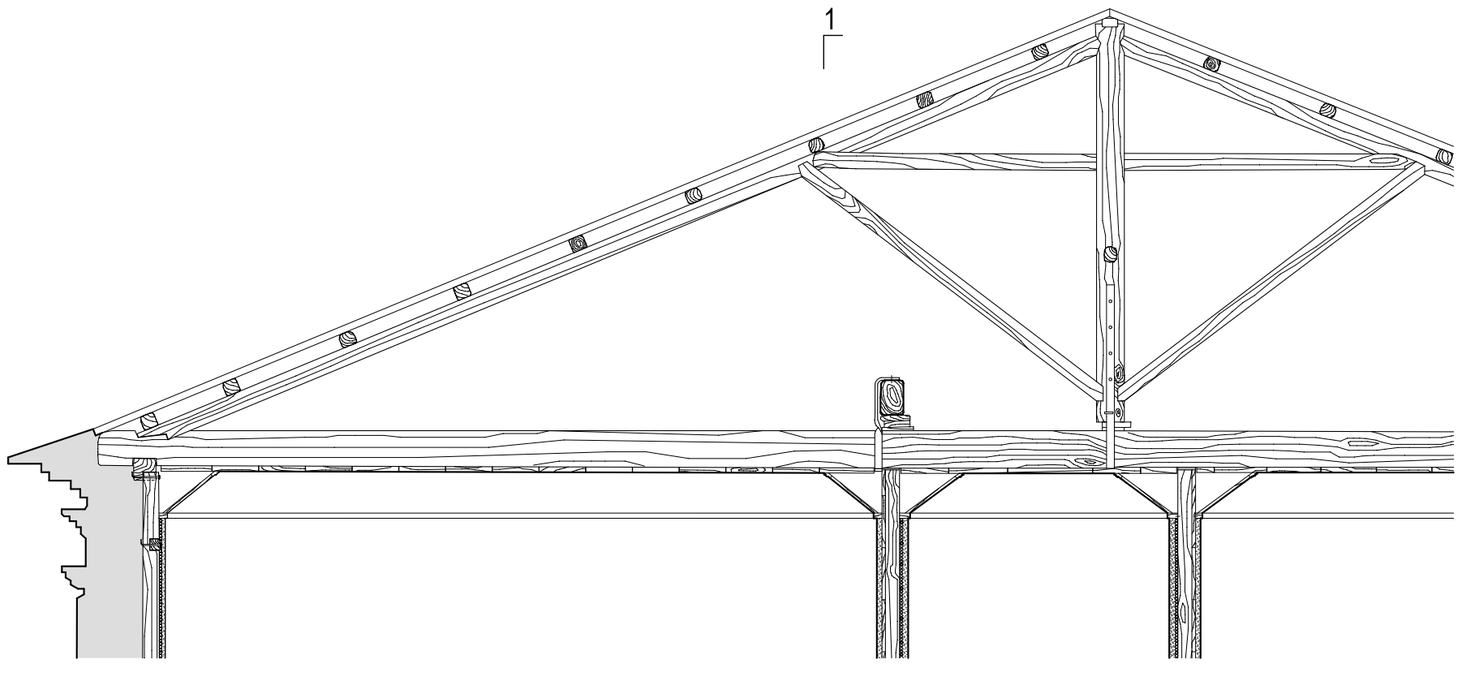
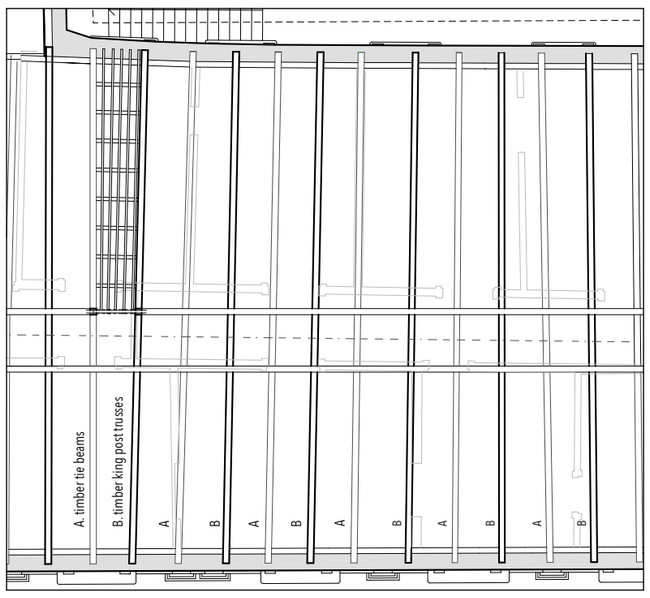


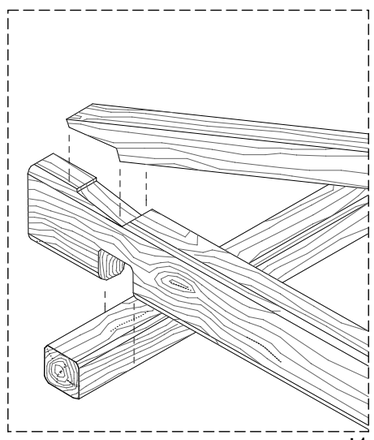
1



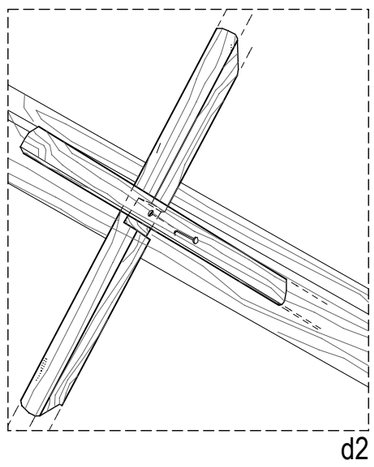


0 2 m

roof structure plan



d1



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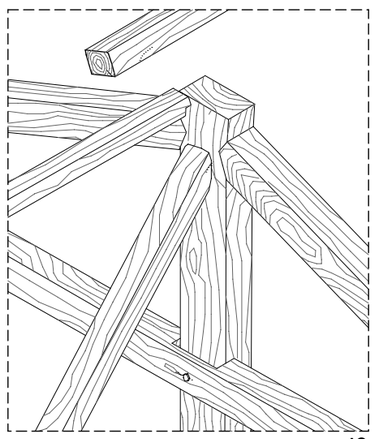

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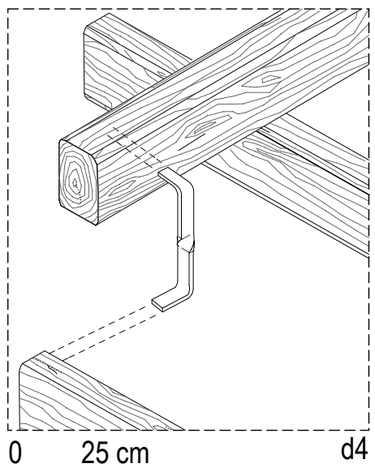

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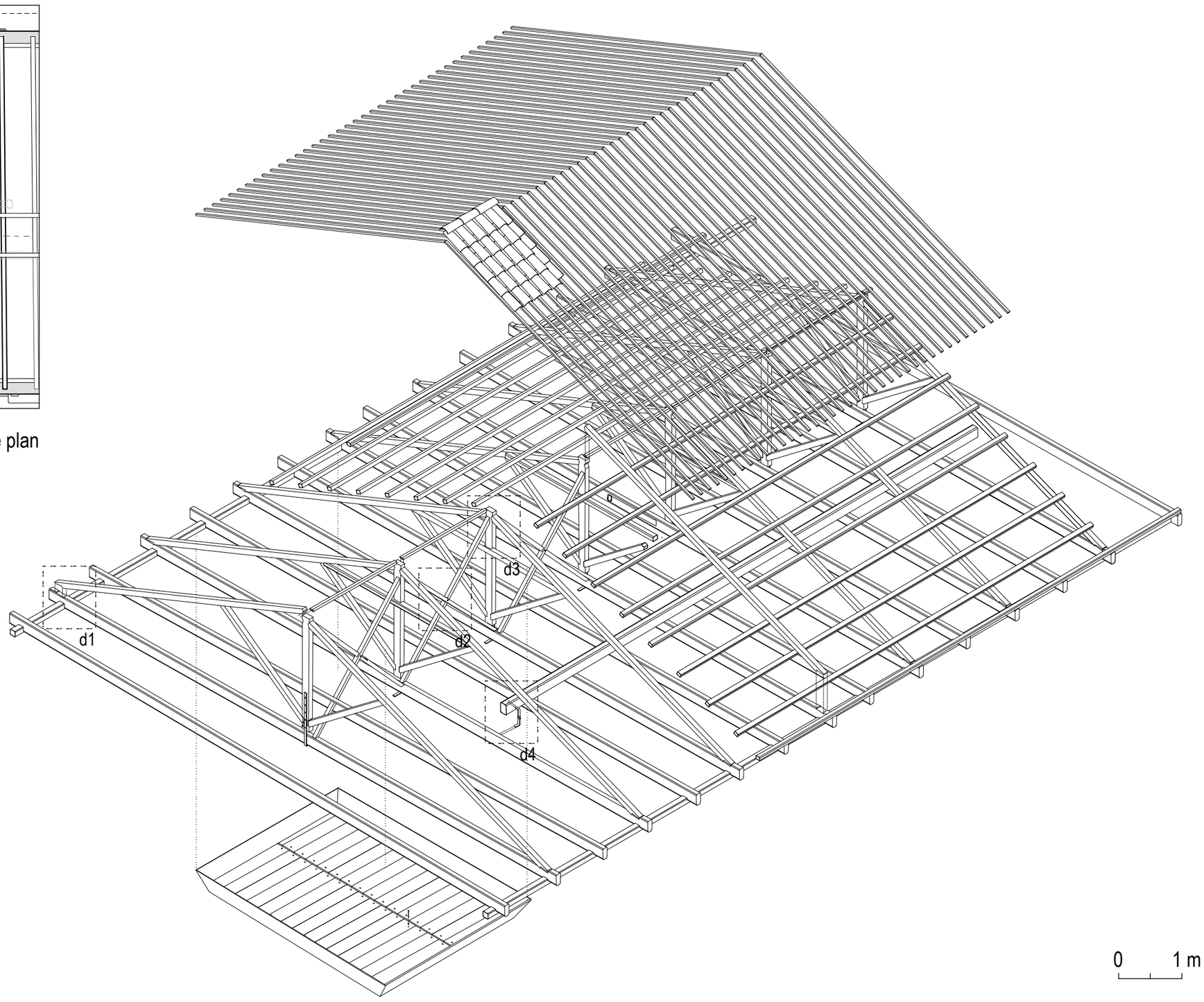
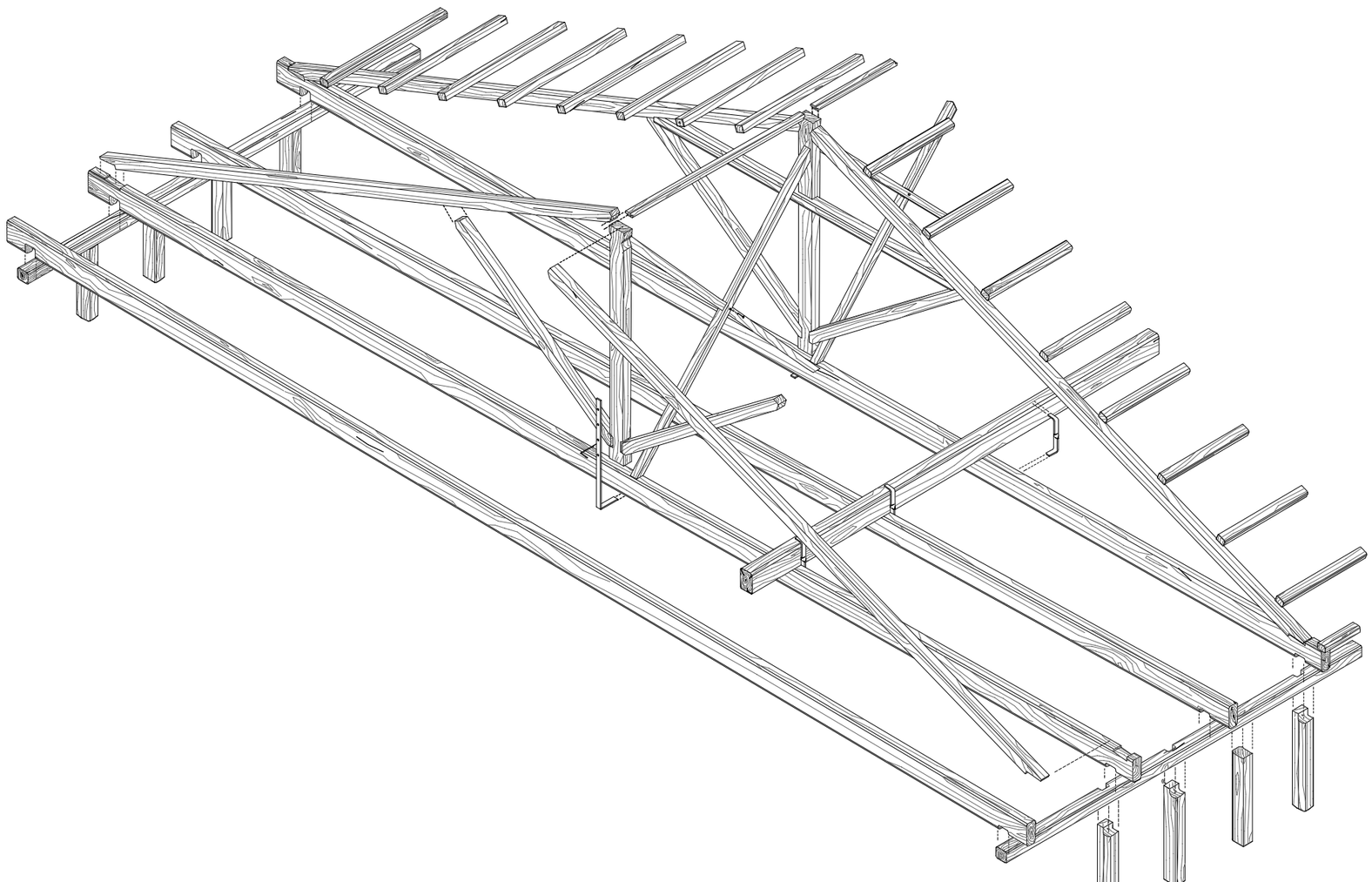
d4



0 1 m



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C.2.2 Photographs



North Elevation



East Elevation



West Elevation

(orthophotographs by Sara Murru)



GROUND FLOOR



0



1



2



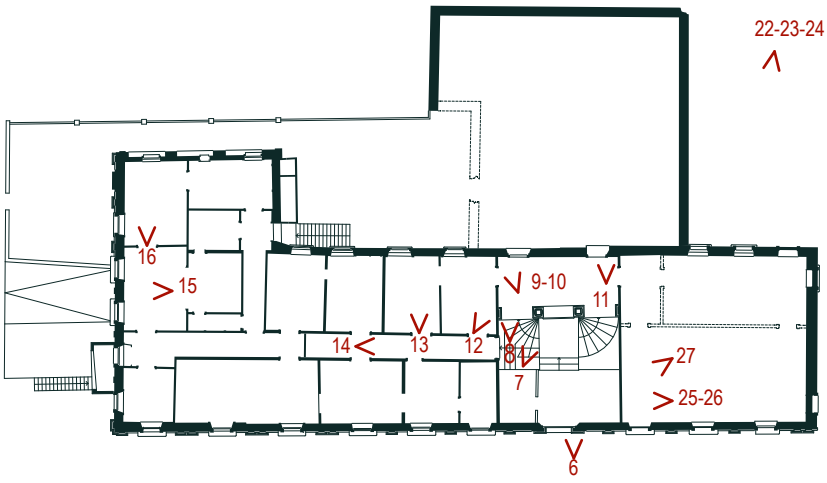
3



4



5



1st FLOOR



6



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8



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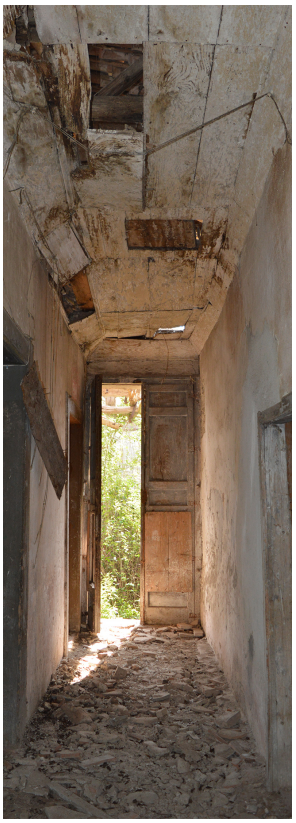

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APPENDIX D

D.1 Glossary of intervention works on historical buildings

Adaptation: Adaptation includes the introduction of new services, or a new use or other changes that enhance the heritage values of the heritage item.

Conservation: Conservation includes a set of intervention works aiming at extending the lifetime of the buildings, such as preservation, protection, maintenance, restoration and adaptation.

Consolidation: Consolidation entails the rebuilding or renewal of the construction components in order to improve the structural capacity (e.g. ductility, resistance capacity, and stiffness).

Examination: Examination is a non-destructive analysis such as on-site observation. Other more sophisticated analyses are excluded in this category (e.g. mechanical and chemical laboratory test, and structural analysis).

Intervention: Intervention includes different works for aim, typology and dimension, such as consolidation, repair, reshaping of building components.

Maintenance: Maintenance aims at minimising the degradation, including a routine monitoring and a management so that the components fulfil their planned functions.

Preservation: Preservation includes the maintenance of the building and every component in order to prevent or delay the deterioration. Any changes of function, shape and state are excluded in this category. A systematic set of works that allows of uses compatible therewith, in compliance with the typical formal and structural features itself.

Reconstruction: Reconstruction is a returning to a known earlier state, by introduction of new material components.

Rehabilitation: Rehabilitation aims to reconstitute the same level of functioning, similar to that previous, but also complete and upgrade for the users' requirements.

Repair: Repair differs from maintenance in that it occurs as timely and exceptional intervention after damage. It aims to firstly intervene to analyse and solve the cause of the harm, and later its effects.

Reshaping: Reshaping implies a change of occupancy or function. It implies a visual and spatial impact.

Strengthening: Strengthening aims to improve the seismic performance by increasing the stiffness and/or the strength of the structural components, or the ductility of individual members. This intervention could imply the introduction of a new structure to increase the lateral force resistance of the original system.

D.2 Glossary of on-site rehabilitation techniques for traditional timber frame wall (TFW)

Preliminary note:

The most common on-site rehabilitation techniques for traditional timber frame wall are below listed according to four sub-components: framework (F) and infill (I), joints (J), and surface finish (S).

Practical solutions should be preceded by specific protocols, as follows:

- placement of propping, as the need arises.
- detailed evaluations from observation or micro-drilling and analysis of structural failures (on-site and laboratory surveys), as input for structural analysis. This anamnesis involves the overall building and its structural component[1].
- site preparation for the protection of each building component from poor climatic conditions (e.g. too dry, too wet or too cold).
- removal of the original surface finish, avoiding any damage on the wall structure, preferably by bolster chisel and hammer and. Corrective measures should be executed on either sides of the wall. Appropriate conservation, repair, and bonding methods should be adopted in presence of frescoes or traditional ceramic tiles (e.g. baseboard).
- careful removal from wall surface of dust and debris, salt deposits, and loose particles by stiff brush. This phase is followed by a natural drying of the wall and is essential to achieve a good adhesion to the substrate mono, multi-layer plaster or cement-based mortar will be placed.
- meticulous documentation of the interventions in all phases (as built record).
- guarantee of good hygro-thermal environmental conditions.
- on-site treatment of the original wooden members with an impregnating varnish or chemical timber protection agent against moisture, cracking and shrinking, fungal and insect attack. In addition, the rustproof treatment of old metallic elements is required for guaranteeing the effectiveness of the interventions on the joints.

[1] "All the activities of checking and monitoring should be documented and kept as part of the history of the structure" (ICOMOS 2003, criterion 3.22)

SCOPE: Wall structure; SUB-COMPONENT: Framework (F)

F1) Removal of local decayed timber elements and replacement with autoclaved timber components

This technique consists of dismantling and replacement of the worn or damaged components with chemical treated wood (i.e. by impregnation in an autoclave). The replaced members are later connected by hot-dipped galvanized or stainless steel nails, and nails set. Cross-halving joints between vertical and horizontal components and also between the X-bracing are the most common traditional connections.

The mechanical properties of the repaired components vary significantly by species, grade, moisture content, and slope of grain of the wooden components. The replaced timber element should be preferably selected with the same species and placed with the same grain orientation of the original component. The most common wood species in Portugal varies from softwood, e.g. *Pinus pinaster, Ait.*, *Pinus sylvestris* to hardwood, e.g. *Quercus faginea*, and *Castanea sativa Mill*. Timber moisture content ("mc") for the replaced components is normally required to stay below 16-20% in order to minimize significant dimensional variations[2]. In case of use of structural glue or epoxy resin, the moisture content should be under 15% and the timber surface without any contamination from resins or gums, oil based paints, preservatives or stains, natural waxes. Further treatments should be carried out by plentiful brushing with insecticidal products (e.g. xylogen).

F2) Substitution of local decayed timber elements with wooden prosthesis using:

Decayed wooden components are replaced by glued laminated wood by epoxy resin mortar, stainless rods or fiber reinforced polymer rods. The timber used for prosthesis should be the same used for the original specimens (see *F1*). The epoxy resin is a two component-system, composed of resin and hardener. It is relatively expensive, but extremely effective in bonding the wood to steel. Being limited in a selected area, this type of repair implies a low increase in mass and cost, low loss of original material, as well as low visual impact. A preliminary surface preparation (e.g. abrasive and chemical cleaning stages) is required. Structural adhesives typically need a week before being covering.

F2 requires specialized workmanship and is subdivided into four different categories of suitably placed prosthesis by using:

F2a) Structural timber glue

This technique consists in attaching prosthesis by structural adhesive in order to improve the original continuity of the structure wall. The most relevant advantages are the invisibility and fast execution, as well as the better distribution of the loads throughout the structure compared to the conventional use of metal fastenings. The main advantage is the irreversibility of this intervention.

[2] The moisture content depends on the general condition in service, exposition to the moisture, water content on the wood associated to the main biological agents, with five different classes of risk (Cruz H.; Nunes, L., 2005). This type, in which there is no ground contact or a risk of humidification, falls into the category of the 1st or 2nd risk classes.

F2b) FRP bars + Epoxy resin

This solution involves the application of diffusion-permeable materials based on high-strength fibres reinforced polymers and epoxy resin. The strips or bars are placed in grooves and covered by a wooden splinter, whose composition is preferably similar to the original one. Structural adhesives typically need a week before being covering. The remarkable strength-to-weight ratio, low visual impact and the fire protection of reinforcing composite strips are the most relevant advantages of this solution.

F2c) Stainless steel rods + Epoxy resin

This technique consists of the placement of stainless steel rod glued to pre-existing post with epoxy resin. It is relatively expensive and more invasive than *F2a*, but highly effective in bonding wood to steel.

F2d) Stainless steel screws

This technique consists of cutting damaged timber members and creating S-shape connections by gluing the two pieces in order to re-establish the continuity of the vertical post. To improve their adherence, it is recommended to place two stainless steel screws to better link the two elements of the vertical post.

SCOPE: Wall structure; SUB-COMPONENTS: Framework (F) and Infill (I)

F3) Introduction of stainless steel structure

This set of measures implies the addition of a new structural system to partially withstand seismic action through the placement of stainless steel reinforcing sections connected to the original wall. The aims are to prevent the occurrence of bending out of the plane and to resolve the discontinuity of the framework, as well as to guarantee combined behaviour of the two systems under earthquakes.

F3a) Stainless steel cross-bracing

The brace with stainless steel is executed by using single diagonal members or cross members linked to the original wall by bolted and welded plates.

F3b) Stainless steel beams/columns with bolted and welded plates

A metallic structure could be introduced to reinforce the timber frame wall in specific sections by means of bolted and welded plates.

F3c) Diagonal damper

This technique is a passive protection devise consisting on an elastic-plastic damper, i.e. a steel rod placed along a diagonal of the walls at full height with the expected results to increase the energy dissipation of the timber frame wall. The rod is laterally restrained by steel plates and profiles and fixed to a guiding bar.

The impact of this technique on timber frame wall is tested by Gonçalves[3] in terms of strength, stiffness, and energy dissipation. This technique is seldom employed due to its low practical and economic feasibility. For these reasons, it is not included in this Macbeth analysis.

[3] (Gonçalves, A.M.; Gomes-Ferreira, J.; Guerreiro, L.; Branco, F. 2014)

SCOPE: Wall structure; SUB-COMPONENT: Infill (I)

After repairing the timber framework, the replacement of the original infill replaced can be executed by using traditional (*I1*)or new (*I2a*, *I2b*, *I2c*) building materials. Otherwise, it cannot be replaced by other materials (*I3*).

I1) Partial removal of infill and repair of the brick or rubble masonry with natural hydraulic lime mortar

This technique consists of a limited repair or replacement of worn or damaged parts by using the original building materials to fill gaps to solve mortar cracks or detachment of the bricks or rubble masonry blocks.

I2) Replacement of infill

This technique consists of a replacement of extensively damaged parts by using new construction materials to fill gaps. The replaced infill can be composed of:

I2a) Clay bricks (or roof tiles) grouted with natural hydraulic lime mortar

This technique consists of the placement of traditional clay bricks or burnt-clay roofing tile from demolished structures. This material raw is later crashed and placed to fill the voids between the timber framework, followed by the placement of natural hydraulic lime mortar. The vertical joints (perpends) of new blocks should not be aligned and every gap filled by small pieces and lime mortar.

I2b) Hollow bricks grouted with cement mortar

Solid or perforated bricks are placed, whose joints by cement-based mortar. Horizontal laying of the blocks is preferable to vertical laying. It should be stressed that the most relevant advantages of this system are the cost-effectiveness and the fast execution, whereas the material compatibility of this technique is questionable.

I2c) Mineral wool

The original infill is replaced by mineral (or glass) wool, selected according to the thickness of the wall structure or different performance (e.g. acoustic, thermic efficiency, fire-safety, and water proofing). In addition to the specific performance of the new panels, the sustainability and the handling in the work site are the major advantages.

I3) No infill

The original infill is completely removed. The fields between the timber frameworks are left empty with the purpose of reusing the timber wall as shelving or as a decorative feature and not as a load-bearing wall.

SCOPE: Wall structure; SUB-COMPONENTS: Framework (F) and Infill (I)

F4+I4) Restore of the wall to its original condition and application of reinforced render

This technique consists of leaving the structure wall as it is and the placement of mortar (approximately 20 mm thick), and of the galvanised metal mesh stretched ridge (or glass fibre reinforced), fixed by nailing staggered in alternate rows, followed by the placement of mortar (approximately 3cm thick). This technique is executed on both sides of the wall. The easy workmanship and cost-effectiveness, as well as increase in compressive strength are the most relevant advantages, whereas non-breathability, limited deformation efficiency, lower tensile strength, increase in loads, non-sustainability and low reversibility are the disadvantages to be taken into account.

SCOPE: Joints (J)

J1) Recovery of carpentry joints

This set of techniques includes the disassembly of traditional carpentry joints and the replacement at very close point to the original one, in order to perform the same function of the original joint. The expected result is the recovery the strength of the original components. Attention should be paid to the design of the construction details and their execution, in order to guarantee the transmission of the seismic actions to the whole system.

The main drawbacks of these techniques are: (i) wood governs failure; (ii) an experienced timber framer is required; (iii) time consuming procedure unless an expensive equipment can be available; (iv) longer assembly time; (v) extreme accuracy required when drilling peg holes for draw boring.

J1a) Wooden pegs and pins

Loosened connections can be wedged out by timber components fixed by hammer or a bit of structural glue. Wooden pegs should be straight grained, slightly tapered and made of hardwood. This technique is not always executable and requires a careful workmanship ad full knowledge of the process.

J1b) Stainless nails

This intervention consists in the placement of modern nails, but assembled according to the number and positioning of the original connections, as tested by Meireles (i.e. the diagonal bars are secured with two nails), or with just one nail in all half-lap connections, as tested by Poletti.[4]

Repairing old nails includes sanding the rusty area down – the nail head – the countersink of the nail, caulking, and the application of rust inhibitor primer. The replacement of the deteriorated nails with galvanized nails is recommended if the old nail heads are sticking out and since it is possible to remove the nails without damaging the surface beneath.

J2) Strengthening carpentry joints

This set of technique aims to improve the physical and mechanical properties of the joints over the original strength. It could be divided into two main categories: (i) ordinary draw materials, e.g. steel (*J2a*, *J2b*, *J2c*); and (ii) composite materials, e.g. fibres and polymer matrix (*J2d*, *J2e*).

J2a) Stainless steel bolts

This technique consists in the insertion of steel bolts (or pins) in pre-drilled holes at the centre of the half-lap connections to tie the timber components. The bolts are fixed with sufficiently tightened screw nuts, in accordance with the limitations on the minimum distances from the borders for bolts and screws *Eurocode 5*[5]. Washers allow a better stress transmission.

J2b) Stainless steel plates with bolts

[4] (Meireles, H.; Bento, R.; Cattari, S.; Lagomarsino, S. 2012) *vs* (Poletti, E.; Vasconcelos, G. 2015)
[5] (EN 2004)

The steel plates are placed into cross-halving connections between vertical and horizontal timber elements and fixed by through-wall steel bolts. The steel plates are commercial (rectangular) or designed with a star-shape, both punched and secured with screws and bolts. The aims is to reinforce the connections, providing more strength and stiffness, and, at the same time, ensuring the required deformation capacity. Steel plates at the connections increase the resistance and the viscous damping of the timber frame wall. Low technical equipment and non-specialized workmanship are the most relevant advantages of this technique. The placement of steel straps for covering splices is advisable in order to keep them stiff and tight.[6]

J2c) Self-tapping screws

The screws are inserted in order to reconnect two cracked portions and thus to solve local buckling, e.g. in the connection of T-frame. The most effective application related to the axial compression is the placement of the two pairs with an angle of 45º. In case the allotted surface is not enough, it is possible to insert the self-tapping screws with an angle of 60° from the post and intersecting the beam, and two pairs with an angle of 45º screwed from the beam and intercepting the notched part of the post.[7] The placement of self-tapping screws shows a high load-carrying capacity if stressed in axial direction[8]. Low intrusiveness and high effectiveness in terms of strength and stiffness are the most relevant advantages.

J2d) NSM with steel flat bars or FRP bars

Fibre reinforced polymer (FRP) can be employed as alternative of either wood or metal prostheses. The bars are embedded into the connections with the near surface mounted technique (NSM) in some points, e.g. at the mid-height connections and at the bottom connections. These bars are made in a composite material, FRP, i.e. where high strength fibres are encased in a polymer matrix. The expected result is the increasing of bending strength of the timber elements. In addition to the advantages of the solution *J2b*, there is also the low visual impact of this technique.

J2e) EBR (GFRP or CFRP)

This technique consists of applying uni-directional (or, better, bi-directional) fibre-glass fabric together with epoxy resin in the groove for impregnation of the fibre with a dry system.

The best material is the carbon fibre reinforced polymer (CFRP). Two different types of pre-impregnated CFRP sheets can be used, i.e. with M or T section. The high increase of flexural strength, shear resistance, axial strength, and ductility, as well as low visual impact – even if more intrusive than *J2d* – are the most relevant advantages. On the other hand, higher cost compared to the steel (employed in *J2b* and *J2c*) and the requirement of skilled labour may be constrain its use. Some companies supply pre-shaped pieces composed of rods already bonded in place and ready to fix to the prepared end of a decayed member.

SCOPE: Surface finish (S)

[6] (Arya, A. S.; Boen, T.; Ishiyama, Y. 2014, 170)
[7] (Poletti, E. 2013, 189-190)
[8] (Chang, W.S. 2015)

Existing surface finish solutions can be divided into four macro-categories: (i) mono or multi-layer plaster (*S1a*, *S1b*), (ii) reinforced layer (*S2*), (iii) lining panels (*S3a*, *S3b*), and (iv) surface film (*S4a*, *S4b*).

S1) Mono or multi-layer plaster

S1a) NHL-based and/or lime-based render reinforced by fiberglass mesh

Lime renders range in strength from feebly hydraulic lime, moderately hydraulic lime to eminently hydraulic lime. Additive cement mixes are excluded in these solutions. The binder and the sand should always be stored dry on the work site. The mixing of the components should be mechanical, such as made by a free fall mixer or better in a contraflow mixer for at least ten minutes.

High technical skill is required during the preparation and the application of one or multi-layer plaster, as well as an accuracy on the selection of the raw products (e.g. well graded and washed sharp sand or river sand in lime renders). The high breathability and the sustainability are the major advantages of *S1a*, whereas the expensiveness and the requirement of skilled workmanship are the many factors that may prevent its extensive use.

S1b) HL or cement-based mortar

These products incorporate ordinary Portland cement that causes adverse effects, e.g. propensity to cracking and peeling, or flaking away of the finish (commonly covered by paint layers). Strength, rigidity, frost resistance, and density of hardened mortar increase insofar the higher cement content increases. The cost-effectiveness and the easiness to control the hardening process with the off-site mixing option are the most important advantages of the cement-based mortar.

S2) Cement-based mortar with metal mesh (or glass-fibre) with acrylic (or polymer) render

This technique allows the stabilization of the surfaces and prevents their cracking. Plaster meshs differ for mechanical and physical properties, e.g. from galvanised chicken wire, welded wire mesh, light type expanded metal, chain wire mesh, and fine woven wire mesh to glass-fibre cloth to plastic netting. Common finishing are acrylic (or polymer) renders. Polymer renders with silicon or nylon have a water repelling property and increase the breathability. Additional strength is provided when nylon or glass-fibre are embedded into basecoat render.

S3) Lining panels

These solutions encompass the placement of external panels. The most common are:

S3a) Plasterboard

Gypsum panels (9.5 mm to 25 mm thick) are vertically fixed to the wall by metal studs walls placed at a constant distance and in case of uneven vertical posts also fixed by wooden pegs or square dowels. In few cases, the metal frame can be also placed horizontally to stiffen the structure. There are various types of plasterboard, fire, moisture and acoustic resistant and also removable for inspections. It should be stressed the easiness (do not require specialized tools or equipment) and the reversibility of this construction system, while tactile and visual impact are very low.

S3b) Strips of wood with lime-based mortar

This technique consists of nailing horizontally the wood panels with nailed gun, such as recycled wood, waferboard or oriented strand boad (OSB), medium-density fibreboard (MDF) or other wood-based panels; or reinforced polymers (plywood). The panels can be hand or machine sawn. A lime-based mortar is applied to fill the gaps, followed by two intermediate coats and a finish coat, applied on the wet surface to protect the wall.

S4 - Film Surface

This set of solutions includes varnishes, lacquers, and paints applied on the wooden components and, in a few cases, also on infill. When this solution is selected, in general, aesthetic purposes rather than functional reasons prevail. Specific preparations of the surface are crucial for the effectiveness of the coating finish. The temperature should stay above 10 °C (50°F) to surfaces that should be dry, clean, and dust free.

S4a) Transparent scumble glaze

This technique consists in applying impregnating varnish, which is an uneven layer of paint over a dry, thin, relatively oil-free base. It contains either alkyd resin solvent binders or acrylic and/or alkyd resin binders that can be thinned with water. This surface film should be checked every two years. The visual impact is extremely different from the original surface wall.

S4b) Coating finish with pigment

This type of covering includes emulsion pains and emulsion lacquers as a pigmented, water-tinned, and solvent-thinned coating and lacquers, with an alkyd resin base. The coating finish should be checked every four years. The visual impact is extremely different from the original surface wall.

D.3 Vendor's description of MCDA methods[9]

Software	Full name	Vendor	Vendor's description
1000Minds	-	1000Minds Ltd.	1000Minds helps with decision-making, prioritization, and discovering stakeholder preferences. Depending on your application, 1000Minds can also help you think about the 'value for money' of alternatives you're considering and allocate budgets or other scarce resources. As well as stand-alone decision tools, we offer customisable processes to include potentially 10s or 100s (even 1000s!) of participants in a variety of group decision-making activities. 1000Minds applies our patented PAPRIKA method – an acronym for 'Potentially All Pairwise RanKings of all possible Alternatives'.
Analytica	Analytica - Beoynd the Spreadsheet	Lumina Decision Systems, Inc.	If you use spreadsheets for building business models or policy analysis, Analytica will be a revelation: Its intuitive influence diagrams let you create a model the way you think, and communicate clearly with colleagues and clients, Its Intelligent Arrays let you create and manage multidimensional tables with an ease and reliability unknown in spreadsheets, Its efficient Monte Carlo lets you quickly evaluate risk and uncertainty, and find out what variables really matter and why.
Craft	Comparative Risk Assessment Framework and Tools		CRAFT is designed to lead natural resource managers through an integrated assessment of the risks, uncertainties, and trade-offs that surround forest and rangeland management. CRAFT helps to identify and clarify objectives, design alternatives, assess probable effects, and compare and communicate risks.
Criterium Decision Plus 3.0	-	InfoHarvest	Direct Tradeoffs, larger models, powerful graphics and extensive options means that CDP 3.0 supports insightful, persuasive decision making faster and for more complex models.
DecideIT	-	Preference	DecideIT enables you to carry out reliable risk and decision analyses. DecideIT packages state-of-the-art decision methodologies and mathematical analysis in an efficient and user friendly software. This decision tool comes with an easy-to-use graphical user interface in which decision trees together with criteria hierchies constitute the main schematic overview of the decision architecture. Such models are very useful in cases of complex decisions, as they provide the decision maker and decision analyst with a graphical presentation of the decision situation at hand and shows the internal relations between options, objectives, and uncertain parameters.
Decision Tools		Palisade Corporation	The DecisionTools Suite is an integrated set of programs for risk analysis and decision making under uncertainty that runs in Microsoft Excel. The DecisionTools Suite includes @RISK for Monte Carlo simulation, PrecisionTree for decision trees, and TopRank for "what if" sensitivity analysis. In addition, the DecisionTools Suite comes with StatTools for statistical analysis and forecasting, NeuralTools for predictive neural networks, and Evolver and RISKOptimizer for optimization. All programs work together, and all integrate completely with Microsoft Excel for ease of use and maximum flexibility.
D-Sight	-	D-Sight	D-Sight help you to solve challenges, analyze data, and drive results by bringing people together to make a decision. It is designed as an interactive and intuitive interface. It provides a framework allowing decision makers to evaluate different alternatives against several criteria and identify the best solution.
GMAA	Generic Multi-Attribute Analysis	Universidad Politécnica de Madrid	GMAA is a DSS based on an additive multi-attribute utility model that accounts for incomplete information concerning the inputs. The system is intended to allay many of the operational difficulties involved in the DA cycle, which can be divided into four steps: structuring the problem; identifying the feasible alternatives, their impact and uncertainty; quantifying preferences; evaluating strategies and performing sensitivity analysis.
Hiview 3	-	Catalyze Ltd	Hiview3 is a PC-based decision modelling tool that supports the appraisal and evaluation of options. It is equally effective for group decision making, such as decision conferences and for individual decisions. With a host of user-defined features, Hiview3 can be configured to address a variety of problem areas, supporting your specific business objectives. Hiview3 enables users to make effective decisions in areas such as Capital Projects, Policy Setting, Strategy Selection, Relocation Issues, Problem Solving and Budget Resourcing.
Logical Decisions		Logical Decisions	Logical Decisions lets you evaluate choices by considering many variables at once, separating facts from value judgments, and explaining your choice to others. Logical Logical Decisions provides a variety of methods for assessing attribute weights, has many results displays and empowers you with many sophisticated features.

[9] This table is adapted from (Mustajoki, J.; Marttunen, M.; FEI 2013, 15-17)

Software	Full name	Vendor	Vendor's description
M-MACBETH	Measuring Attractiveness by a Categorical Based Evaluation Technique	Bana Consulting Lda	MACBETH is an interactive approach that requires only qualitative judgements about differences to help a decision maker or a decision-advising group quantify the relative attractiveness of options. It employs an initial, interactive, questioning procedure that compares two elements at a time, requesting only a qualitative preference judgement. As judgements are entered into the software, it automatically verifies their consistency. A numerical scale is generated that is entirely consistent with all the decision maker 's judgements. Through a similar process weights are generated for criteria.
MakeIt-Rational	MakeItRational – Analytical Hierarchy Process Software	MakeIt-Rational	MakeItRational is a decision support software based on Analytic Hierarchy Process (AHP), which organizes and simplifies decision-making.
MCDA-Res	-	University of Aegean	MCDA-Res aims at providing guidelines that enable integrated Analysis of RES investments. This process will aid in deciding about the appropriate project to be implemented
MESTA	MESTA - Decision Support Tool	Metla	MESTA enables you to perform holistic and multi-objective decision analysis based on selected decision criteria. During the use of the application you will define your own acceptance thresholds for each decision criteria.
OnBalance	-	Quartzstar Software Ltd	OnBalance helps separate what you measure from how you value it. The interface is specifically designed for group decision making, as most of the difficult decisions are between good schemes, each supported by one or more managers.
PlanEval	Plan evaluation	Swedish University of Agricultural Sciences (SLU)	Alternative plans generated in PlanWise can be compared systematically by structuring the decision problem into components, put relative weights on these components either by pairwise comparisons or direct weighting, and finally conmputing a total (relative) value for each plan. The method used is called Analytic Hierarchy Process (AHP).
Promax	-	Cogentus Consulting Ltd	Promax enables organisations to robustly underpin decisions. Unlike other tools, such as a spreadsheet, what sets it apart is that it is a purpose made decision tool. It is leading edge with massive flexibility, powerful visualisations all backed up by academic rigour.
PUrE2	PUrE2 Software	PUrE INTRAWISE	Alongside the existing pollutant and impact modelling capabilities built into the PUrE software building models and indoor air quality models have been added. In addition existing models and tools such as Life Cycle Assessment, Human Health Analysis and Multi-Criteria Decision Analysis have been substantially improved.
TESLA	-	Quintessa	TESLA aims to support decision makers when faced with complex decision problems. It provides a means to break a decision down into a hierarchical structure, simplifying the problem and presenting it in such a way that information can be easily gathered and categorised. TESLA does not automate the decision-making process but provides valuable support to the decision maker.
The Decision Deck project	-	Decision Deck Consortium	The Decision Deck project aims to developt Open Source software tools implementing MultiCriteria Decision Aid (MCDA) techniques which are meant to support complex decision aid processes. One of the main features of these software solutions are that they are interoperable in order to create a coherent ecosystem.
V.I.P. Analysis	V.I.P. Analysis - Variable Interdependent Parameters Analysis	University of Coimbra	V.I.P. aims to support the selection of the most preferred alternative among a list, considering the impacts of each alternative on multiple evaluation criteria. It is based on an additive aggregation model (value function), accepting imprecise information on the value of the scaling coefficients (scaling constants, which indirectly reflect the relative importance of the each criterion).
V.I.S.A. Decisions	Visual representations of information, Interactive results charts, Sensitivity Analysis	SIMUL8 Corporation Ltd	V.I.S.A. software supports the decisions with multiple, tough to balance, factors, and for problem context where no option matches all of the criteria perfectly; or for decisions where more than one person has a say in how the decision is made. It does not tell you the "right answer", it lets everyone involved see for themselves what the best overall decision is, weighing up all the factors using a considered and sound process.
Web-HIPRE	HIerarchical PREferences on the Web	Systems Analysis Laboratory, Aalto University	Web-HIPRE is a web-version of the HIPRE 3+ software for decision analytic problem structuring, multicriteria evaluation, and prioritization.
WINPRE	Imprecise Preferences for Windows		Winpre is an implementation of techniques based on the propagation of imprecise preference statements in hierarchical weighting. PAIRS and Preference Programming methods are both implemented in Winpre.

D.4 Macbeth outputs: overall performances in three selected scenario models

D.4.1.1 Table of scores, 1st scenario

Note: [all lower] represents an overall reference whose performances on all criteria are equal to their lower references.[10]

1st scenario (28 options)

Options	Overall	MC	SR	SA	VTA	MP
[all upper]	100.00	100.00	100.00	100.00	100.00	100.00
TF01	88.67	100.00	19.19	100.00	100.00	61.62
TF04	84.55	93.14	29.29	87.26	100.00	61.62
TF10	84.55	93.14	29.29	87.26	100.00	61.62
TF82	74.99	65.66	19.19	100.00	100.00	47.47
TF86	74.99	65.66	19.19	100.00	100.00	47.47
TF102	74.99	65.66	19.19	100.00	100.00	47.47
TF03	74.72	100.00	20.20	100.00	44.00	61.62
TF90	71.13	59.60	29.29	87.26	100.00	47.47
TF96	71.13	59.60	29.29	87.26	100.00	47.47
TF105	71.13	59.60	29.29	87.26	100.00	47.47
TF111	71.13	59.60	29.29	87.26	100.00	47.47
TF06	70.61	93.14	30.30	87.26	44.00	61.62
TF12	70.61	93.14	30.30	87.26	44.00	61.62
TF02	62.03	86.28	19.19	100.00	11.00	61.62
TF85	61.04	65.66	20.20	100.00	44.00	47.47
TF104	61.04	65.66	20.20	100.00	44.00	47.47
TF05	57.91	79.41	29.29	87.26	11.00	61.62
TF11	57.91	79.41	29.29	87.26	11.00	61.62
TF59	57.81	100.00	16.16	68.63	44.00	5.05
TF107	57.19	59.60	30.30	87.26	44.00	47.47
TF113	57.19	59.60	30.30	87.26	44.00	47.47
TF89	56.46	51.52	19.19	100.00	44.00	47.47
TF63	53.39	93.14	25.25	54.55	44.00	5.05
TF71	53.39	93.14	25.25	54.55	44.00	5.05
TF22	53.26	58.59	20.20	91.18	44.00	27.27
TF123	52.91	58.59	13.13	91.18	44.00	27.27
TF127	51.45	65.66	13.13	71.57	44.00	27.27
TF45	50.89	65.66	13.13	68.63	44.00	27.27
	Weights :	**0.3200**	**0.0500**	**0.1900**	**0.2500**	**0.1900**

[10] (Bana e Costa, C.A.; De Corte, J.M.; Vansnick, J.C. 2015, 61)

D.4.1.2 Table of scores, 2nd scenario

2nd scenario (39 options)

Options	Overall	MC	SR	SA	VTA	MP
[all upper]	100.00	100.00	100.00	100.00	100.00	100.00
TF13	78.40	93.14	70.59	66.67	100.00	61.62
TF07	77.19	93.14	70.59	60.61	100.00	61.62
TF01	76.16	100.00	19.19	100.00	100.00	61.62
TF04	74.26	93.14	29.29	87.26	100.00	61.62
TF10	74.26	93.14	29.29	87.26	100.00	61.62
TF16	72.57	93.14	47.47	60.61	100.00	61.62
TF99	68.87	59.60	70.59	66.67	100.00	47.47
TF114	68.87	59.60	70.59	66.67	100.00	47.47
TF93	67.65	59.60	70.59	60.61	100.00	47.47
TF15	67.40	93.14	71.57	66.67	44.00	61.62
TF82	66.46	65.66	19.19	100.00	100.00	47.47
TF86	66.46	65.66	19.19	100.00	100.00	47.47
TF102	66.46	65.66	19.19	100.00	100.00	47.47
TF09	66.19	93.14	71.57	60.61	44.00	61.62
TF03	65.16	100.00	20.20	100.00	44.00	61.62
TF90	64.72	59.60	29.29	87.26	100.00	47.47
TF96	64.72	59.60	29.29	87.26	100.00	47.47
TF105	64.72	59.60	29.29	87.26	100.00	47.47
TF111	64.72	59.60	29.29	87.26	100.00	47.47
TF108	64.62	44.44	70.59	60.61	100.00	47.47
TFO6	63.26	93.14	30.30	87.26	44.00	61.62
TF12	63.26	93.14	30.30	87.26	44.00	61.62
TF117	63.03	59.60	47.47	60.61	100.00	47.47
TF18	61.57	93.14	48.48	60.61	44.00	61.62
TF116	57.86	59.60	71.57	66.67	44.00	47.47
TF14	57.86	79.41	70.59	66.67	11.00	61.62
TF110	56.65	59.60	71.57	60.61	44.00	47.47
TF08	56.65	79.41	70.59	60.61	11.00	61.62
TF02	55.62	86.28	19.19	100.00	11.00	61.62
TF85	55.47	65.66	20.20	100.00	44.00	47.47
TF104	55.47	65.66	20.20	100.00	44.00	47.47
TF107	53.73	59.60	30.30	87.26	44.00	47.47
TF113	53.73	59.60	30.30	87.26	44.00	47.47
TF05	53.72	79.41	29.29	87.26	11.00	61.62
TF11	53.72	79.41	29.29	87.26	11.00	61.62
TF89	52.44	51.52	19.19	100.00	44.00	47.47
TF119	52.03	59.60	48.48	60.61	44.00	47.47
TF17	52.02	79.41	47.47	60.61	11.00	61.62
TF38	50.39	51.52	71.57	57.58	44.00	27.27
	Weights :	**0.2000**	**0.2000**	**0.2000**	**0.2000**	**0.2000**

D.4.1.3 Table of scores, 3rd scenario

3rd scenario (29 options)

Options	Overall	MC	SR	SA	VTI	MP
[all upper]	100.00	100.00	100.00	100.00	100.00	100.00
TF13	78.24	93.14	70.59	66.67	100.00	61.62
TF07	77.94	93.14	70.59	60.61	100.00	61.62
TF15	71.34	93.14	71.57	66.67	44.00	61.62
TF09	71.04	93.14	71.57	60.61	44.00	61.62
TF16	68.92	93.14	47.47	60.61	100.00	61.62
TF99	67.31	59.60	70.59	66.67	100.00	47.47
TF114	67.31	59.60	70.59	66.67	100.00	47.47
TF93	67.01	59.60	70.59	60.61	100.00	47.47
TF14	63.24	79.41	70.59	66.67	11.00	61.62
TF108	63.22	44.44	70.59	60.61	100.00	47.47
TF08	62.94	79.41	70.59	60.61	11.00	61.62
TF18	62.04	93.14	48.48	60.61	44.00	61.62
TF116	60.41	59.60	71.57	66.67	44.00	47.47
TF110	60.11	59.60	71.57	60.61	44.00	47.47
TF75	58.01	93.14	67.65	34.34	44.00	5.05
TF117	57.99	59.60	47.47	60.61	100.00	47.47
TF67	57.66	93.14	67.65	27.27	44.00	5.05
TF38	54.30	51.52	71.57	57.58	44.00	27.27
TF17	53.92	79.41	47.47	60.61	11.00	61.62
TF30	53.81	51.52	71.57	51.52	44.00	26.26
TF129	53.56	51.52	68.63	24.24	11.00	62.63
TF100	51.95	44.44	70.59	66.67	11.00	47.47
TF115	51.95	44.44	70.59	66.67	11.00	47.47
TF51	51.92	59.60	64.65	27.27	44.00	26.26
TF101	51.80	44.44	70.59	63.64	11.00	47.47
TF94	51.65	44.44	70.59	60.61	11.00	47.47
TF109	51.65	44.44	70.59	60.61	11.00	47.47
TF95	51.50	44.44	70.59	57.58	11.00	47.47
TF119	51.10	59.60	48.48	60.61	44.00	47.47
	Weights :	**0.2500**	**0.3900**	**0.0500**	**0.1300**	**0.1800**

APPENDIX E

E.1 Appended publications



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Gaiola vs. *Borbone* System: A Comparison between 18th Century Anti-Seismic Case Studies

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ABSTRACT

This article briefly discusses the seismic-resistant heritage of the 18th century, circumscribed in Lisbon's *Baixa Pombalina* (post 1755) and *case baraccate* of Southern Italy (post 1783).

A comparison of these anti-seismic systems is discussed through the architectural principles and the mechanical behavior. It is shown that, despite the wide diversity of cases and the different geo-historical conditioning, both systems arise from an intuition of the compound seismic efficiency, the typical pragmatism of the enlightenment period and an interpretation of the classic composition code.

Two specific case studies, a private building in *Baixa Pombalina* (Lisbon) and the Bishop's Palace of Mileto (Calabria region) are compared. We briefly analyze: (i) configuration and structural principles; (ii) characteristics of the materials; and (iii) seismic behavior.

A standardized spatial morphology closely linked to traditional construction techniques positively determines the seismic response and it is one of the key common factors in this heritage to be preserved.

In both cases, the architectural and structural choices are crucial to the seismic response of the building and must be respected as an identity of a specific technical knowledge. Moreover, this materiality represents a historical continuity of the community's memory that requires transdisciplinary, critical understanding, and preservation.

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architectural heritage; *casa baraccata*; earthquake-resistant structures; *gaiola Pombalina*; timber structure

1. Research aims

The aim is to establish analogies and differences between composite structures in the Mediterranean area to perform a critical analysis for the safeguard of the architectural heritage, dated from the late 18th century. This work contributes to multidisciplinary knowledge of the traditional techniques that influence the spatial configuration and represent an identifying cultural element.

This article intends to deepen the knowledge related to the impact of the original architectural and technical solutions in the seismic response of the building, through the analysis of the two models in the light of their geometrical and structural characteristics.

The comparison of the anti-seismic heritage, in Italy and in Portugal, should help to clarify a current methodological approach to the heritage safeguard. From a state of art that integrates areas generally addressed separately, this article focuses on two specific cases, analysed from a typological starting-point. The selection of these two specific cases depended also on the actual possibility to observe directly the structure, alongside the historical and experimental research. Differences arise in the two cases related to the development of density of occupancy, the walls structure, and the mechanical behavior.

2. Introduction

As a result of the catastrophic earthquakes in Portugal (1755) and Southern Italy (1783), official military engineers promoted radical reforms for urban and architectural planning.

Since the last decade of the 18th century a heterogeneous and vast heritage was established based on mixed systems: the compact urban grid in Lisbon and the reconstruction of dispersed urban centers in southern Calabria.

The *Borbone* system and to a greater extent the *Pombalino* system owe their wide spreading to two key factors: (i) high efficiency of the construction model based on timber and masonry; and (ii) cost effectiveness, thanks to the reuse of local (or existing) materials. Due to the extraordinary technical and

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formal quality and the remarkable consistency of this anti-seismic heritage, an extensive literature covering various fields of research may be found.

Regarding the Portuguese case, França (França 1983) and Rossa (Rossa 1998) deepen and contextualize the socio-cultural environment, whereas Mascarenhas (Mascarenhas 2004) reports the typological evolution and characterization through several examples of *Baixa Pombalina* buildings (1755/1880). In the Italian case, detailed studies have mapped out the groundwork to a recognition of the value of *case baraccate*, namely Maretto (Maretto 1975) analyzing the urban setting and building typological features in some Calabrian centres and Principe (Principe 1976) with incidence on urban, historic, and political aspects. Furthermore, it is relevant to mention Tobriner (Tobriner 1997) highlighting the strength of the constructive principles and Barucci (Barucci 1990) focusing on a diachronic study and the extraordinary variety of Italian treatises during the 19th century. Significant and recent contributions to knowledge concerning historical, constructive, and experimental aspects of the system are carried by several authors (Galassi et al. 2014; Ruggieri 2005, 2013; Ruggieri, Tampone, and Zinno 2013).

Comparative studies and research covering seismically active regions worldwide, as India, Turkey, Central America, and the U.S. also assimilating the Portuguese and Italian cases were carried out by Langenbach (Langenbach 2007). With regard to studies on the materials characterization and the efficiency of the structural system, it can be said that scientific literature on historic timber frames is fairly recent, particularly in the Italian case.

In the context of experimental campaigns, researchers from the Portuguese National Laboratory for Civil Engineering (LNEC) and more recently from the University of Minho and from the Instituto Superior Técnico (IST) have investigated various aspects of the performance of the *gaiola*. In particular, numerous cyclic tests were carried out in order to clarify: (i) the contribution of the internal timber-masonry wall and of each component, namely timber and masonry, to the global seismic resistance of the structure; (ii) the influence of the wall filling material and of the joints in the mechanical behavior; and (iii) reinforcement techniques (Santos 1997; Lourenço, Vasconcelos, and Poletti 2014; Cardoso et al. 2005).

In the case of Santos' experimental campaign the cyclic tests were performed in real wall sections removed from buildings (Santos 1997; Silva 2002), as well as in scale models characterized by a replica of the original geometry and traditional joints (Meireles et al. 2012). The latter assessed strengthening techniques namely steel plates with different configurations and steel flat bars inserted with the Near Surface Mounted (NSM) technique (Poletti, Vasconcelos, and Jorge 2014).

A model of the *borbone* wall was reproduced in September 2013 at the CNR/Ivalsa Laboratory in Trento to be subjected to cyclic actions based on UNI 12512 loading protocol (Galassi et al. 2013; Ruggieri 2014; Ruggieri and Zinno 2015).

However, a systematic comparison of architectural principles and construction techniques was never tackled, especially from a multidisciplinary perspective. Detailed studies on experimental research relating to the strengthening interventions, the systematic inventory of the several types and the principles for safeguard the *casa baraccata* are still lacking. A deep understanding of the architectural heritage in all its aspects is essential in order to evaluate a correct conservation and rehabilitation approach.

The heritage rehabilitation requires a careful analysis of the available techniques for structural improvement, seeking a weighted compromise between the paradigms of contemporary use and the cultural value of the historical building.

3. Architectural and structural principles

3.1. General principles

Due to reasons related to a contingent pragmatism in emergency conditions and the specific historical period, these anti-seismic models take over classical code, as sagacity construction (*fabrili subtilitate*) is achieved through modularity and accuracy (*officinatoris exactio*) in the detail.

Four principles in earthquake-resistant systems may be outlined: (i) a regularity of the plan and elevation development; (ii) the behavior of the building as a whole unit; (iii) the joints and overall ductility; and (iv) the reduction of the mass compared to an ordinary masonry building. These principles are now analyzed in more detail.

The composition of the buildings of the late 18th century, both in Portugal and Italy is characterized by a clear layout with the repetition of proportional order systems. This feature is evident in the representations included in the *Cartulário Pombalino* (AA.VV. 2006) and the ones drawn by Eng. Ferraresi in Vivenzio's treatise (Vivenzio 1783). The regularity of the layout both in vertical and horizontal sections induces regularity in the distribution of mass and stiffness.

In both cases the design and execution were based on a metric module where the whole and each part were commensurable. This commensurability was achieved through the fixed module (palms) in elevation and plan to economize the constructive process.

This control measure differs from previous medieval architecture. During reconstruction this measure was based on human dimensions, as an abstract quantity applied indiscriminately to all the artifacts and had some variations depending on the location of construction. Greater importance was given to the elevation, in the rigid logic of the alignments of the openings and the constant rate between the solid-void relationship in the surface.

The difference of the two cases in density of occupancy (higher in the Portuguese case) lies in the historical-geographical setting. Both cases seek the relation between the construction technology, typology, and urban planning.

Specifically in Portugal, the facades composition should be inspired from the neo-classic code, namely from Serlio studies (Duarte 2004) and reflected the streets hierarchy. The buildings are grouped in rectangular and homogenous blocks (70 × 25 m^2) with a narrow central yard (45 × 2 m^2) (Ramos and Lourenço 2004). Typically, four floors were built including the ground floor with a commercial use and the attic with a renting apartment.

It respected the same height of the urban complex, so as to facilitate similar dynamics and a better seismic performance, through *"row"* behavior in which every building benefits from the presence of the confinement assured by the contiguous one.

The layout is quite simple and is repeated in height, comprising two apartments per floor with a central staircase ("*right-left*" plan) or one apartment per floor ("*singular*" plan), a functional solution to a rental use. The so-called "*right-left*" plan has a bi-axial symmetry distribution and accounts for 54% of the *Pombalino* heritage (Mascarenhas 2004). In the Italian case, instead, a modest type of townhouse prevails, also with biaxial symmetry and with one or two floors.

The second principle, the behavior of the building as a whole unit, is achieved through the connection of the structural elements in the three dimensions of the fabric, thus reaching an overall balance.

According to this principle both systems have the structural strength of a three-dimensional behavior because of the good compatibility and the combined work of the orthogonal walls. The box-like effect that is achieved through the solidarity between the structural elements results in a lower vulnerability of the entire compound. In fact, during an earthquake, the shear wall avoids or reduces the possibility of collapse, acting in the parallel direction to the imposed action with stiffness greater than the perpendicular one.

In the *Pombalino* building (1755–1870) the principle of vertical continuity of timber walls was peremptorily respected along the whole height. The connection of all the structural components was carefully executed and assures that the structure is one single unit reacting in a flexible way to the stresses acting during an earthquake.

The third principle—overall ductility—is the basis for the good performance of the system under earthquake strain. Under seismic actions an ordinary masonry, as well as timber members, have a predominant brittle behavior. In the case of wood, the ultimate limit state and/or the collapse is reached predominantly under the linear field.

With these composite structures the excessive flexibility of the wood is limited by the presence of the filling materials; on the other hand, the elasticity of the timber frame manages to bring the wall to its original position, at least for moderate displacements. Furthermore, the system is suitable to dissipate seismic energy thanks to the presence of the timber structure nodes that are not rigid enough to result in brittle fractures. Moreover, ductility is enhanced by the friction generated between the elements of the walls, as well as at the interface between wood frame and masonry filling. The energy dissipation also takes place thought cracks in the mortar joints and stones expulsion.

Finally, the fourth principle is a result of the specific strength of the system. Due to the lowest specific weight and high strength (in comparison with a structure entirely in masonry), the seismic forces produce a moderate acceleration in the framed structure, lower than most of other kinds of structure, such as reinforced concrete or unreinforced masonry. Moreover, considering the timber structures redundancy, there is an effective solidarity in case of failure of a structural element and other force-carrying elements compensate and prevent a collapse of the entire system (Ruggieri 2014; Galassi et al. 2013; Ruggieri and Zinno 2015).

3.2. Timber-framed system: Frontal vs. Borbone wall

The aforementioned systems are based on the use of collaborating materials, masonry and wood, whose influence determines the overall behavior of the building under cyclic loading.

A unique set of construction principles prevail in Lisbon (with innumerable alterations over the centuries), as opposed to Calabria region, where many structural variants are spread over that territory. The heterogeneity of the Calabrian heritage is possibly explained by the nature of the Italian code (*Istruzioni Reali*, 1784), without precise information and dimensional drawings, but only qualitative descriptions of the

system to be adopted. Another important distinction should be highlighted: in Portugal, it may be said that these buildings are *wooden architecture*, given the predominance of this material in terms of quantity and performance; in the many Calabrian variants, however, it is still *stone architecture*.

Therefore, the Portuguese wall seems to depart from the Roman model, *Casa Graticcio*, in Herculaneum (Geremia 2014) to a greater extent than that of Calabria. In Lisbon, the timber execution is the starting point and center phase of the entire constructive process and not simply, as in the Vitruvian case, to stiffen the wall or optimize the execution time.

The *"gaiola"* is a cage formed by an orthogonal grid of vertical panels ("*frontais*") and timber floors. Each panel consists of a set of triangles (a non-deformable shape): improving the shear strength of the wooden elements vertically, as well as under the horizontal loads. An almost perfect system was achieved by the solidarity among different structural elements (also multiple of the palm) to form St. Andrew's crosses, where the connection is essential for the general bracing of the structure.

With regard to the plan spatial configuration, *Pombalino* buildings present the wooden cage as a three-dimensional structure stiffening the load-bearing walls, assuring solidarity between every structural element and with "*tabiques*" (internal partition walls made of wood and mortar).

Regarding the materials characterization, the system is constituted by a wooden frame filled with heterogeneous material. In the same building various types of wood species and genus may be found, often *Pinus pinaster, Castanea sativa, Quercus ilex, Pinus silvestris, Pinus palustris, Quercus robur*, and *Quercus suber*. The filling is made of irregular blocks of limestone and/or clay bricks, gravel, and small ceramic elements and mortar. A particular type of mortar was prepared on site with clayish sand and quicklime with the addition of small portions of tallow (vegetable or animal fat). The result was a remarkably waterproof mortar (Santos 1994).

The *Borbone* system, instead, is based on timber wood wrapped up in masonry. The local wood, Calabrian Chestnut, is the most frequently used. However, the reduced availability of timber and the long return period characterizing the southern earthquakes were the causes for a progressive simplification, which also happened in the *Pombalino* case.

Unlike the Portuguese case, where the filling masonry was completely irregular, in *Borbone* wall, rectangular blocks, roughly squared in different dimensions, were adopted. The external walls of the *casa baraccata* were built with wood framing, while the inner, thinner walls (25 cm) were made of wood and uncoated masonry, or sometimes with simple frames filled with brick, like *gaiola*, however without connections to the floor.

To sum up, the Portuguese system may be designated by *timber frame walls*: a framework of timber infilled with masonry, while the Italian system may be designated by *masonry reinforced with timber frames*: stone and bricks walls with a wooden skeleton (Ruggieri 2014).

The function of the timber elements is substantially different. In the half-timbered model of Lisbon, the bearing system works under static field and dynamic loads. Conversely, in the *casa baraccata*, the wooden frame does not take part, or only in a limited way, in static field; under dynamic action, the wooden skeleton provides to the masonry an additional tensile strength.

Another significant difference arises in the ground floor construction. In *Pombalino* building, the wood frame was not executed in the ground floor where masonry arches are the structural element that carries loads to this level masonry walls. This principle is generally respected in order to avoid fire destruction and wood degradation due to humid environments, as well as conferring stiffness to the system on the base. In Calabria, the wooden framework was applied in the walls on all floors (two) to a maximum height of 28 palms, and the arches and stone vaults were, on the contrary, prohibited.

4. Case studies: *Pombalino* building vs. Bishop's Palace of Mileto

4.1. Brief historical analysis

The Portuguese reconstruction after the 1755 earthquake was developed *in situ* over previous building remains as one major option from the authorities. On the contrary, at Mileto (as in 20 other centers of Calabria, out of 53) the decision was to rebuild in an area located 20 km apart from the original urban core (Centro Servizi Culturali Vibo Valentia 1982).

The two cases, however, have in common the technicality operating in solving public problems, like fire hazard and public health, by the widening of streets, limiting the height and keeping regular the geometry of the buildings, the system of collecting sewage water. Moreover, both reconstructions were planned with the aim of overcoming the structural flaws of the building before the earthquakes of the 18th century. In Portugal these problems are a consequence of salient elements in the facade, global weight, disproportion between height of the building and street width and geometric

irregularity. In Italy the problems are predominantly conditioned by a poor construction practice.

Analyzing, the two case studies, the major difference is that the *Pombalino* building is part of an urban block and the *casa baraccata* is an isolated block. The four-story building is localized on a quarter of the *Baixa Pombalina*, bordered by a medieval area. It's a so-called *singular* plan, with a stair on the side of the property and with a small rear patio (2.00 × 2.90 m^2). The organization of the whole building is articulated with a sequence of four internal walls, parallel to the street. There are no corridors and internal circulation is made from room to room.

This case study is an example of a *Pombalino* building that has been altered, as the continuous balcony was not part of original design (Figure 1). However, for the typology layout and the material characterization it fully respects the set of *Pombalino* rules.

The facade is classic, defined on either side by an order of pilasters that are interrupted on the fourth floor by a balcony. The facade is characterized by: the alignment of the ashlars around the openings; an "empty" to "full" ratio of one and the inequality of height in relation to the adjacent buildings, due to the addition of extra floors. The exceptions to this composition are the ground and the mezzanine floors.

The Calabrian case is a complex intended to the Bishop's house and a seminary. It dates back to 1784, a year after the macro earthquake that struck Mileto and other cities of the Tyrrhenian coast. The building has an east-west orientation and is characterized by an elongated shape that fits in the regular town plan designed by Eng. Francesco La Vega and Arch. Ferraresi (Figure 2).

The architectural design is neoclassical mannered built in two stages. Despite substantial changes, like volumes added on the back south side, infill panels and wide openings on the east elevation of the ground floor, the original layout is still legible.

The wide front wing of the building has two levels, the ground floor and a mezzanine level. It is characterized by an alternation of openings, with an "empty" to "full" ratio of approximately 4/11. Every window is framed by a side order of pilasters and by triangular or curved-shape brick gables alternating on top.

The front is asymmetrical: the main entrance is not centrally placed and the first three divisions are separated by an order of a pilaster, while in the other divisions this separation is based on a double order of pilasters. As can be deduced from some fragments, the pilasters were originally characterized by thick grooves (Figure 3).

The basement, in bossage, reaches the windowsill of the ground floor's windows. The doorway is enhanced by the stretched transom with curved sides on the keystone and at the base of the pilasters with a floral motif. The staircase with three flights connects with a central corridor parallel to the longitudinal front. The roof is wood trussed and the eaves height is approximately 6.50 m.

4.2. Survey and characterization

In both cases, a very thick lime plaster and mortar normally hides the timber structure, making it difficult to identify the structure condition (Figure 4).

In the Portuguese case study, the wall and ceiling finishing layers (mortar and plaster) were completely



Figure 1. *Pombalino* case study: Building in Rua dos Fanqueiros n.110[a]–114, Lisbon.

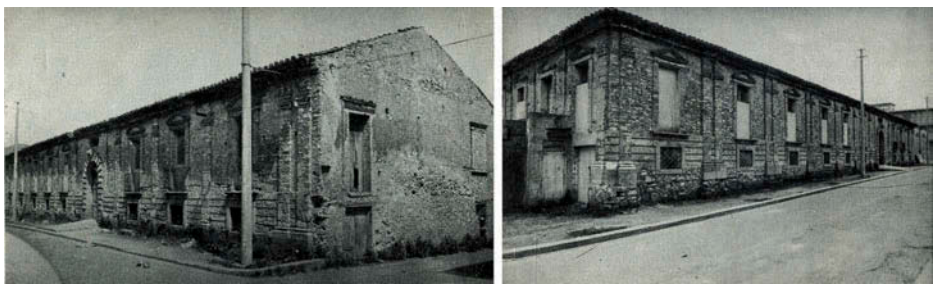

Figure 2. *Borbone* case study: Bishop's Palace of Mileto (Centro Servizi Culturali Vibo Valentia, 1982). © Centro Servizi Culturali Vibo Valentia. Reproduced by permission of Centro Servizi Culturali Vibo Valentia. Permission to reuse must be obtained from the rightsholder.



Figure 3. *Borbone* case study: Bishop's Palace of Mileto, basement detail.

removed to check the different structural materials and their degradation condition within the scope of an ongoing rehabilitation project; in the Italian case, the external walls are only partially visible. In the *Pombalino* building, three main types of walls were detected: (i) external wood framed masonry walls; (ii) rubble stone masonry walls (partition of the lot); and (iii) internal timber-masonry structural walls (Figure 5).

These interior walls are divided into three vertical modules of Saint Andrew's crosses in all floors but the mezzanine floor, with two modules (Figure 6). This conformation is the antithesis of the initial rule defined

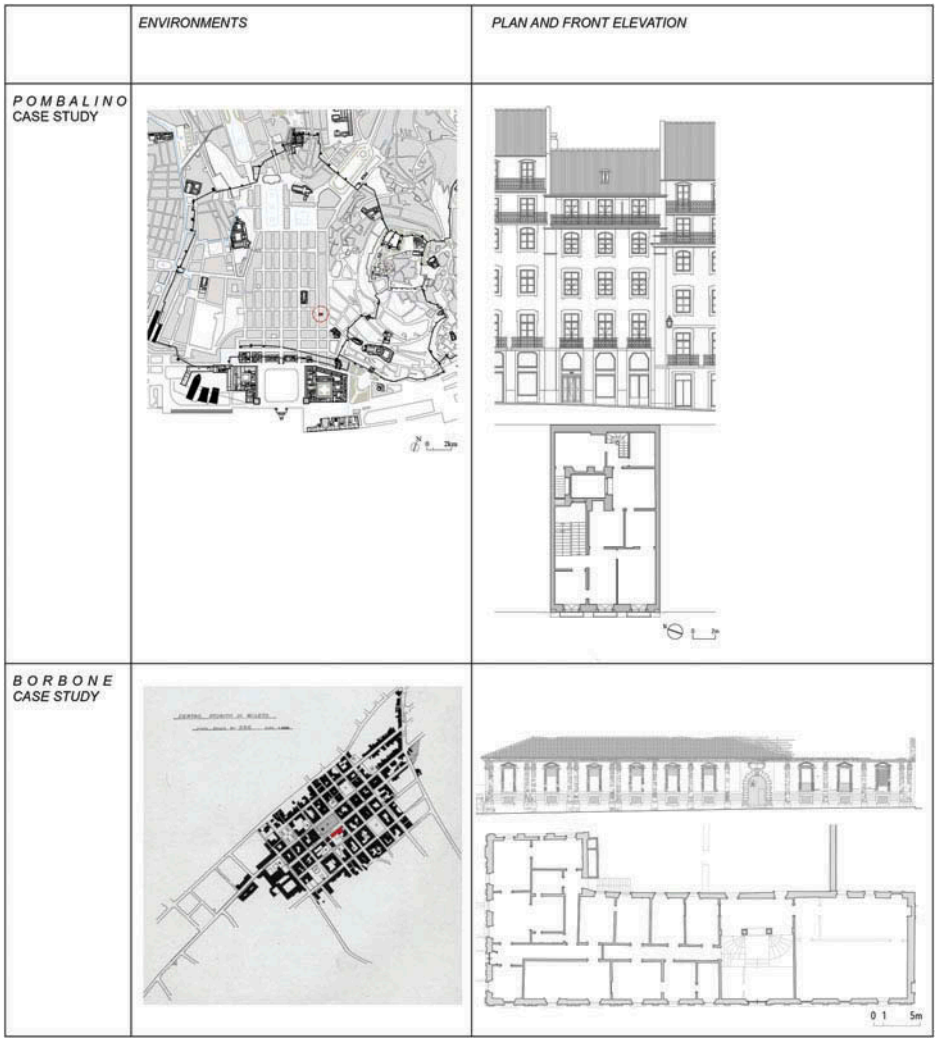

Figure 4. *Pombalino* case study versus *Borbone* case study. Images © Santa Rita Arquitects (top right), Centro Servizi Culturali Vibo Valentia (bottom left) and A. Lonetti (bottom right). Reproduced by permission of Santa Rita Arquitects, Centro Servizi Culturali Vibo Valentia, and A. Lonetti. Permission to reuse must be obtained from the rightsholders.

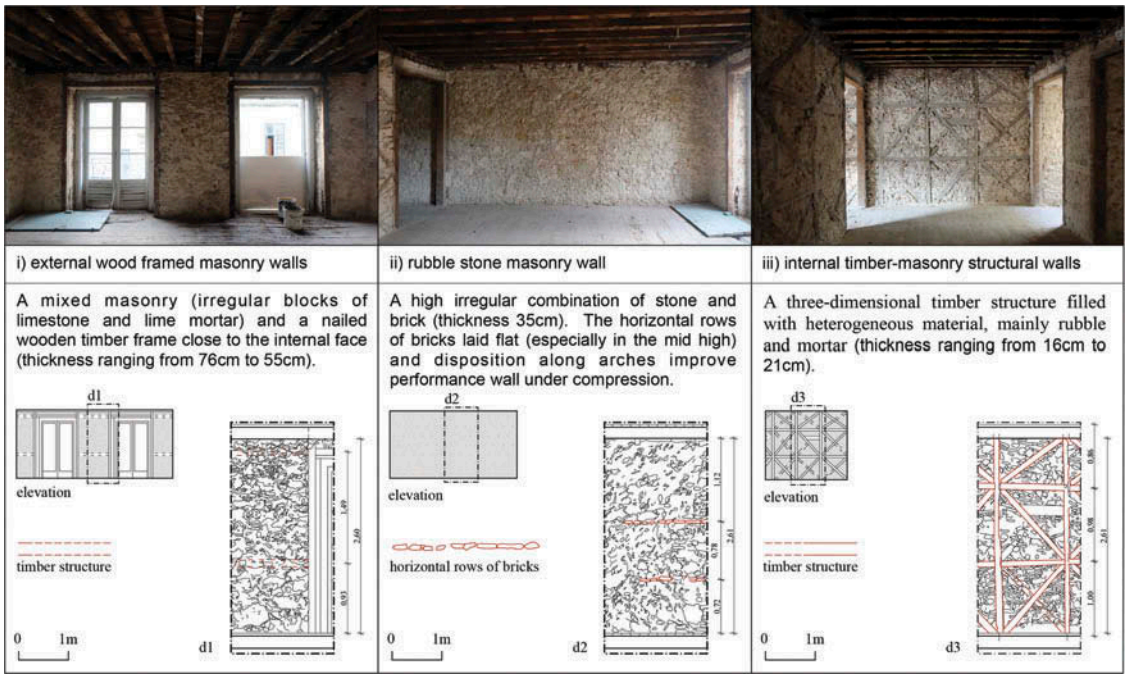

Figure 5. *Pombalino* case study: i) external wood framed masonry walls; ii) rubble stone masonry walls; internal timber-masonry walls.

after the earthquake, which involved three of these vertical modules in the first floor and two modules in every other upper (Mascarenhas 2004).

The vertical wood elements (so-called *"prumos"*) reach a height of more than one floor and have a variable section (approximately 15 × 30 cm in mezzanine, 10 × 16 cm in upper floors). This structural continuity allows a greater mechanical strength of the structure. In some cases, as in the mezzanine level, the horizontal elements are longer than the dimension of the module, supporting the diagonal and vertical elements (Figure 7).

The round and squared wooden beams in floors became progressively smaller, from the ground to the upper floors. The filling of the triangular voids was carried out with bricks and irregular stones and lime mortar (Figure 7—F02). In some cases, the bricks are arranged in diagonal position, while the stones are horizontally arranged.

The carpenters fabricated the wooden skeleton continuously over the height of the building, properly shored, before the filling of the frames. There is a hierarchy in the structural response; the wood structure has the greatest burden, both under static and horizontal actions and the masonry filling cooperates providing additional stiffening (Figure 8).

The timber elements are notched or connected by rounded head nails or iron ties. Half lap joints are frequently used, adapted *in situ*, improving the connection and then the stiffness (Figure 9). The timber joints are carried out with more caution and effectiveness on the lower floors. To avoid inlays (that would reduce the mechanical strength and would require more processing), diagonals uprights are often not coplanar (Figure 6).

Differences arise in the characterization of Calabrian walls, which have more regular composition than the Portuguese case. The construction technique is a mixed masonry with brick and granite splitters, combined by a fairly stiff mortar. Almost rectangular blocks roughly squared in different dimensions prevail. It should be inferred that the only processing performed in the quarry is the cutting to obtain two smooth and parallel faces. In-situ laying was performed filling joints using bricks, probably from collapsed buildings after the earthquake. As in the Portuguese case, the bricks are horizontally arranged and the mortar stands out for a good cohesive capacity (Figure 10).

In both cases, on the top of the internal walls, a summit wooden beam supports the timber beams, bound by half-timbered joints (Figures 6 and 10). The beam allows a distribution of the loads transmitted by floor beams and mainly improves the solidarity between orthogonal walls. Regarding the exterior walls, on the top a wooden beam guarantees adherence only by friction.

Regarding the *Pombalino* case, two aspects about the floor structure are outlined. First, a reduced spacing between wood beams, probably to achieve a greater stiffness since there is a more efficient distribution of the earthquake actions to shear walls; moreover, this low spacing also supports in preventing possible risks of tilting in the case of horizontal actions perpendicular to the plane. Second, transversal wooden elements are included between

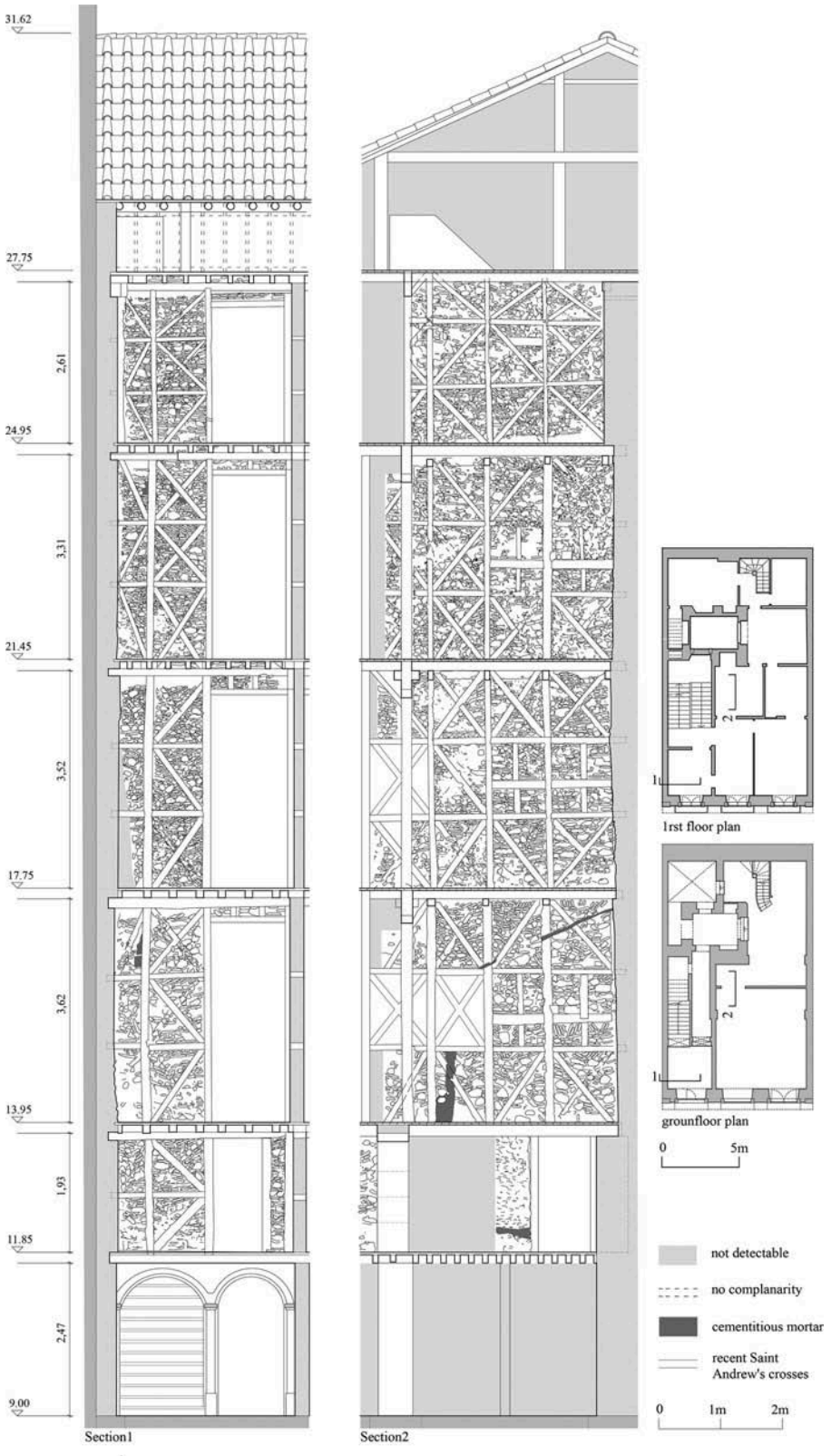

Figure 6. *Pombalino* case study: partial sections and plans.

main wood beams, to assure a bi-directional structural performance and bracing to avoid lateral instability in bending.

In the mezzanine level, the low arches, whose pushing action is contained by principal walls, are parallel to the front facade, on one side and on the other by *gaiola*, that

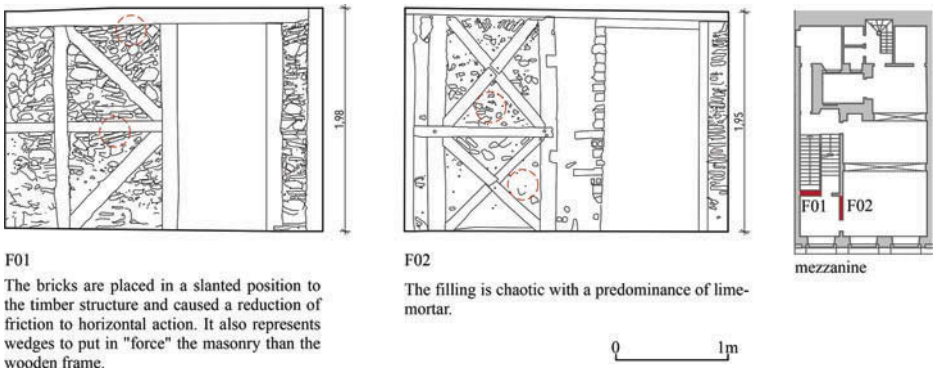

Figure 7. *Pombalino* case study: comparison of two walls (type iii) located in the mezzanine floor.



Figure 8. *Pombalino* case study: internal view.

support longitudinally the staircase. The floors are perpendicular to the main facade, with the exception of the ground floor. The floors should be considered as flexible diaphragms, confining the relative out-of-plan displacements of parallel masonry walls (Cardoso et al. 2005).

5. Conclusions

This article attempts to underline a critic perception of the local anti-seismic culture of the 18th century, in Italy and Portugal, outlining strengths and weaknesses in *Pombalino* and *Borbone* heritage. The common principles highlighted could be considered innovative and particularly efficient to achieve a better seismic resistance.

Through two examples illustrated with a detailed survey, it is shown how the structural effectiveness is based on the coherence between architectural composition, technique and structure. The aim of this article is to underline the importance of the cultural authenticity of these structures. The rehabilitation of this seismic-resistant heritage should preserve its historical value, principally based on this coherence, with the aim of improving its resistance even if not attempting to make the building "adequate" (Giuffrè 1992).

The art. 7 of the *"Carta Italiana del Restauro"* (1931) has defined the preference for the conservation of the original techniques, distributional layout and constructive scheme is highly recommended, where reasonably feasible. Every conservation charter published afterwards confirmed this procedure.

Due to a recent significant increase in the number of interventions on this heritage (especially in Lisbon), it is necessary to highlight that its historical value embrace the whole building and not just isolated elements (facade or stairs), as determined in ICOMOS guidelines (ICOMOS 2001).

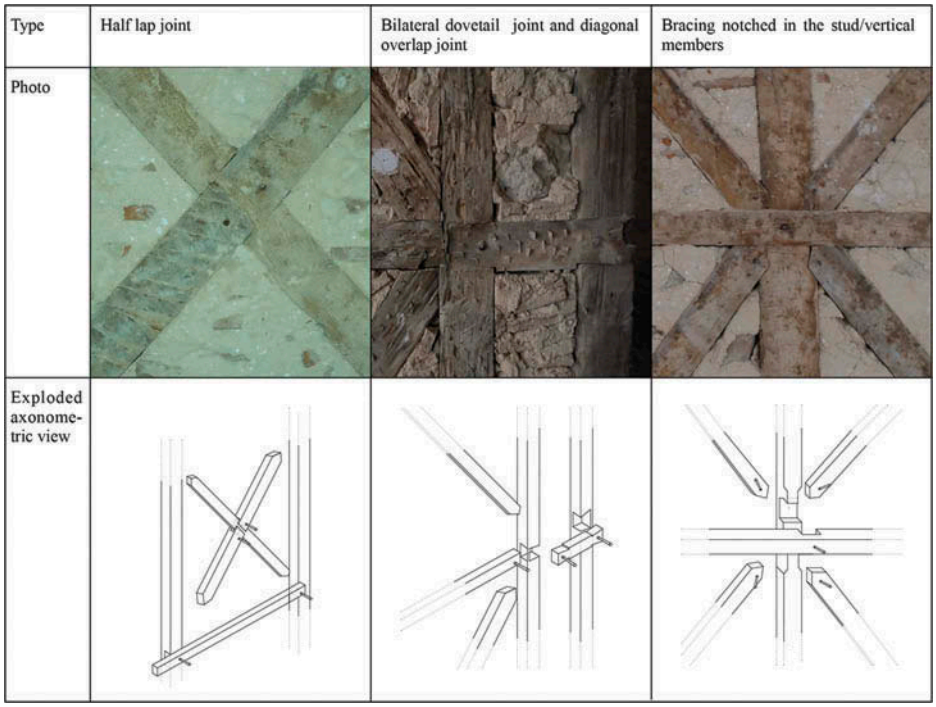

Figure 9. *Pombalino* case study: details of timber connection.

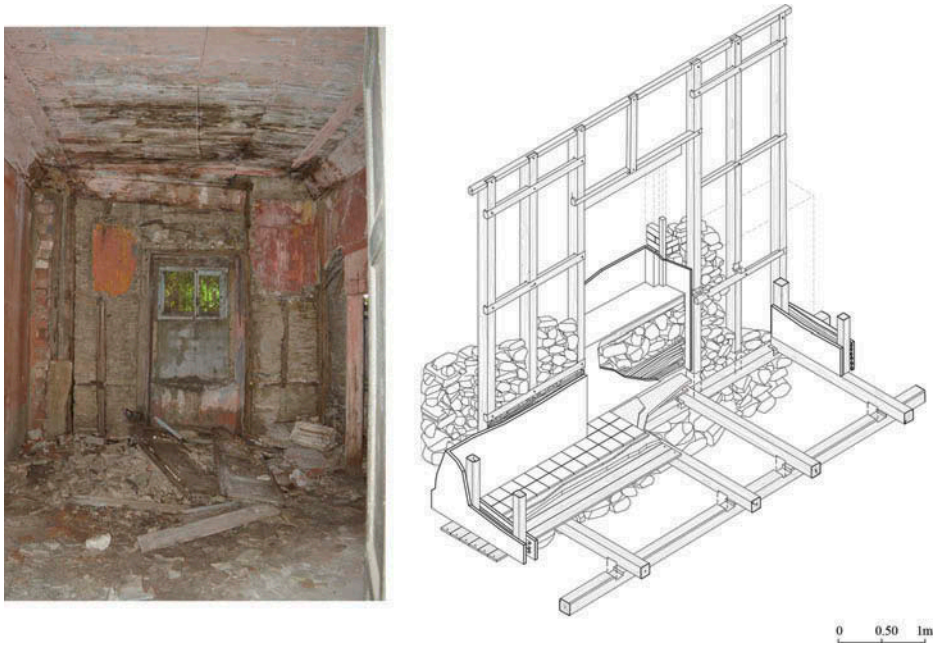

Figure 10. *Borbone* case study: photo and axonometric view of external wall reinforced with timber frames.

Despite the fact that these buildings are frequently the property of several owners, a systemic global view is essential in order to integrate the different interventions that each one may perform to rehabilitate the fabric. It is important to assess and make a choice on the distributive character and the spatial distribution of stiffness, avoiding substantial changes.

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Structural Permanence in Pre- and Post-Earthquake Lisbon: Half-Timbered Walls in Overhanging Dwellings and in *Pombalino* Buildings

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ABSTRACT

Timber-framed walls represent a structural permanence in Portugal before and after the 1755 earthquake. Despite improvements made in the *Pombalino* buildings (late 18th century) for seismic design purposes, comparisons can be drawn with the use of mixed timber-masonry structure in overhanging medieval houses.

The structural efficiency of medieval overhanging dwellings is due to the reduction in the weight from the lower to the upper floors, the ductile behavior, and the connections between the infill frame and the floor structure.

A survey of examples still standing in Lisbon is carried out by the authors through archival dataset and on-site analysis. Special attention is paid to the degree of authenticity and state of conservation. Dissonances and continuities in the original construction and subsequent refurbishment are analyzed in three cases that are selected for their localization and remarkable architectural or typological features.

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KEYWORDS
Construction technique; half-timbered wall; overhanging dwellings; *Pombalino* buildings; structural authenticity

Research aims

This research strives to further knowledge about infill-frame constructions in Portugal, namely Lisbon's overhanging dwellings, through a literature review, archival data, and on-site analysis. More specifically, this article aims to underline the technical continuity between the medieval construction system and the seismic-resistant heritage (18th century), despite differences in their architectural composition, building typology, and seismic behavior.

The analysis of overhanging dwellings covers the following: (i) the main architectural and structural features; (ii) a comparison with the *Pombalino* construction system; (iii) an inventory of the remaining examples and causes of alterations; and (iv) principles for safeguarding purposes.

The authors highlight the importance of preserving the structural authenticity of this building typology, conceived not only as evidence of local material and construction culture but also as the basis of the 18th century anti-seismic system.

1. Introduction

Over the centuries, the timber-framed wall was used for interior partitions and/or external facade (on the upper floors) of poor residential houses in the Mediterranean basin (Turkey, Greece, and Portugal) and Northern European countries (France, England, Germany, Switzerland) (Santos et al. 1990) due to the availability of materials, cost-effectiveness and rapid execution.

Before the 1755 earthquake, two main building typologies are found for the use of timber frame on upper floors in Portugal: (i) *casas de andares em ressalto* (overhanging houses) in Porto, Lamego, Guimarães and Chaves; and (ii) *casas com águas em bico* (buildings with the roof ridge perpendicular to the plane of the facade—triangular facade) in the south, namely in Setubal and in Alcácer do Sal (Pinho 2000).

These construction systems combined the use of timber framework, typical of Northern Europe, and masonry, traditional in the Mediterranean area. However, a geographical subdivision is clearly schematic, as suggested by the Lisbon case where different construction systems converged and even merged together in a few examples (Figure 1) (Fernandes 1991; Santos et al. 1990).

The overhanging houses represent very cheap and widespread constructions in Europe from the sixteenth century (Oliveira and Galhano 1992). In Lisbon, also referred as *casas com fachada em tabique*, most of these buildings have few floors (two or three, and rarely four)

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Figure 1. Building with overhanging volume and triangular facade (XVI century) in *Rua dos Cegos* nr 20-22, Lisbon. © S. Stellacci. Reproduced by permission of S. Stellacci. Permission to reuse must be obtained from the rightsholder.

with a total area from 40–150 sqm (Santos et al. 1990). Along the narrow and winding streets, the half-timbered walls of the medieval houses (so-called *frontal* because it constituted the main facade) were employed in order to increase the interior area or add extra floors (Santos et al. 1990).

The popular residential housing that withstood the 1755 earthquake in the city accounts for barely 3% of the existing building stock (Sequeira 1999) (Figure 2) and several of Lisbon's traditional infill-frame constructions remained unscathed.

The heterogeneous group built before the 1755 earthquake could be divided into three categories: (i) with high quality masonry; (ii) with lower quality masonry; and (iii) with overhanging floors (Pinho 2000).

This research focuses on the latter category, overhanging houses. The significance of this category lies in: (i) the small number of existing cases; (ii) specific architectural and structural features; and (iii) the construction technique that would evolve into the *Pombalino* system (AA.VV., 2000; Appleton 2008).

Over the centuries, the term *frontal* has been associated in Portugal to the traditional timber framework even though it was mainly applied as an internal structure wall during the recovery of *Pré-Pombalino* houses in the post-earthquake reconstruction and, in particular, in the 18th century *Pombalino* buildings (those built for financial profit) (Appleton 2008).

Despite the historical value and structural importance of the overhanging dwellings, there is still a lack of research into this building typology and into the medieval houses in Lisbon generally, in terms of their material characterizations and seismic analysis. Indeed, Lisbon Municipality has provided the chrono-typology survey of the building stock, framed within the municipal legislative system (CML, 2010).

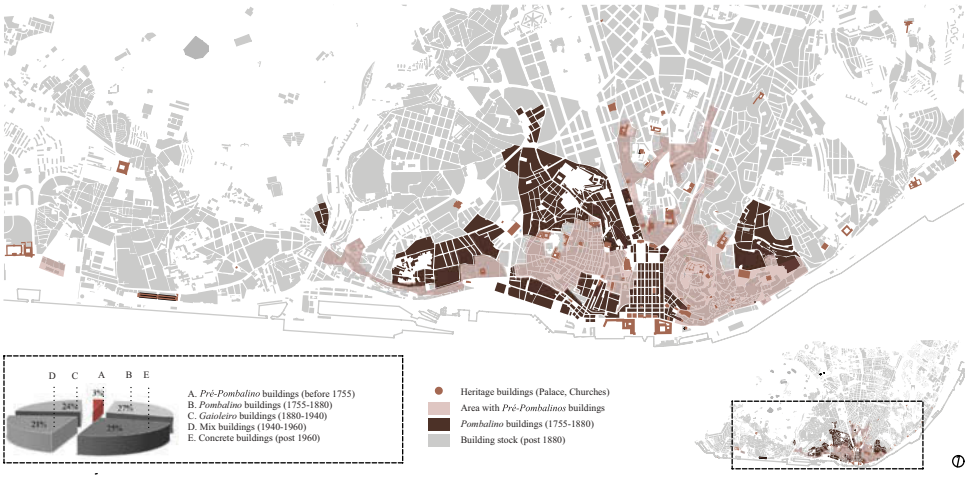


Figure 2. Lisbon building stock divided by chrono-typology categories. © S. Stellacci. Reproduced by permission of S. Stellacci. Permission to reuse must be obtained from the rightsholder.

Analyses of the medieval construction process and two cases studies (e.g., *Rua Achada* nr 23–25, *Largo da Achada* nr 1, demolished) (Santos et al. 1990) and an adulterated overhanging house (e.g., *Rua da Guia* nr 1/7, Lisbon) (Appleton 1991) were carried out by the *Portuguese National Laboratory for Civil Engineering* (LNEC). Pinho provided a brief description of the material characterization and mechanical behavior (Pinho 2000) but an analysis of the structural adulterations, seismic vulnerability and retrofitting methodologies is still required.

This article provides an inventory of the medieval overhanging houses divided in accordance with the degree of structural and architectural authenticity, and an overview of the main causes of adulteration based on the archival dataset and physical evidence.

2. Historical framework

2.1. Historical precursors of half-timbered constructions

The medieval overhanging dwellings and the Roman *maeniana* (constructions with cantilevered balconies) have in common the presence of jetties to increase the interior area and the *opus craticium*.

According to Festus, the *maeniana romaenensia* derives from a censor named Maenio, who allowed the construction of timber overhangs for the Roman spectacles in 318 BC (Festus 1889). These overhanging walls were made with timber frames (*arectarii* and *transversarii*) filled with a siliceous or testaceous conglomerate (lath and plaster) and abundant mortar (*coagmentum*) (Gros 1997). The presence of the conglomerate, rather than a solely wooden-based construction, reduced the fire hazard (Geremia 2014). However, this mixed technique was not recommended in Pompeii and Rome because it was deemed unstable and flammable. In the case of Herculaneum instead, more prone to experimentations and influenced by nearby *Neapolis*, this construction technique was found predominantly within *domus* with *atrium* and also where the floor area could be increased. *Casa a Graticcio*, a rental house in Herculaneum (Insula III, 13–15, 1st century AD) provides ancient evidence of this construction technique. Thin dividing walls, originally covered with wattle and plaster, were constituted of wooden skeleton of square frames (without bracing elements) and filled with *opus incertum* (Dell'Orto 1993; Geremia 2014).

In Portugal, the timber framework of the overhang volumes was imported from Northern Europe via the northern cities (Guimarães, Chaves, Lamego and Viseu among others). In fact, the total absence of the half-timbered structure within rural Portugal and the small urban centres indicates that this building technology is non autochthonous. It was probably imported by cities with thriving and frequent trade relations with Atlantic Europe (Fernandes 1991; Santos et al. 1990).

Lisbon is an area where different cultural and technical practices converged and also where the know-how of naval carpenters played a decisive role. The local workmanship traditionally employed in shipbuilding was used for the reconstruction of Lisbon, organized by the royal public works office (AA. VV 2000; Farinha 1997; França 1987; Penn, Wild, and Mascarenhas 1996).

Analogies can be made between the Roman house and the medieval overhanging dwelling. In fact, both examples were characterized by the use of infill timber framework in the external wall. On the other hand, as described below, the *Pombalino* system avoided the timber skeleton on the facade (on external side) but it is included as an internal load-bearing structure that acts as efficient shear walls braced with the floor structure (Appleton 2003; Penn, Wild, and Mascarenhas 1996).

2.2. Legislative framework in the Middle Ages

As described by Vitruvius, the main drawbacks of the braced timber frame with masonry infill are the exposure to adverse weather and, above all, its inflammability (Gros 1997). However, in spite of the frequent fires in Lisbon over the Middle Ages (namely in 1369, 1373, 1531), the timber frame continued to be used in the poor construction buildings for centuries (Carita 1994; Zurara 1949).

Considerable efforts were made to improve the medieval urban structure through the legislative regulations *Cartas Régias* (1499–1502) issued by King D. Manuel I. This code forbade all large overhangs due to transit problems and fire hazard, and it ordered the destruction of all the timber overhangs within a period of 6 months; noncompliance was punishable by fine (Carita 1999). The above-mentioned code prohibited wood in the external walls and limited overhanging volumes to one and a half palms. The flat and aligned facades (stone masonry and lime mortars) replaced the volume cantilevering out in timber frames (Carita 1999). As Carita pointed out, the major difference between the medieval and the modern city is indeed that timber structures are no longer used in urban areas. However, the timber framework did not disappear over the 18th century but was the internal skeleton of the *Pombalino* buildings.

2.3. After the 1755 earthquake

The construction in the aftermath of the 1755 earthquake involved the estuary area, the *Baixa Pombalina* (62 quarters of 23.5 hectares) and other urban tissue (Figure 2). *Pombalino* built stock was regulated by norms on

dimensional and morphological features, which was conceived to be innovative (França 1987): several aspects were discarded and forbidden, such as the irregularity in plan and elevation, narrow streets, high verticality, as well as the overhanging volumes.

Nevertheless, the royal engineers retained a few traditional aspects in the structural solution (e.g., half-timbered walls) and in the urban settlement (e.g., organization by crafts) (Farinha 1997; França 1987; Mascarenhas 2004; Penn, Wild, and Mascarenhas 1996). In addition, the transition between the 18th and 19th centuries was much smoother in the historical urban fabric that had been less affected by the earthquake (e.g., *Bairro Alto, Santa Isabel*) due to spatial, architectural, and typological constraints (Carita 1994).

Like other countries (Southern Italy, Greece, Turkey), damage from the earthquake was highly selective. The following categories of structure were considered more vulnerable: (i) taller buildings compared to smaller constructions up to three floors; (ii) the heaviest buildings with larger walls spans; and (iii) the buildings with overhanging volumes (Farinha 1997).

However, it was observed that the building typology with a wooden structure overhang seemed to offer a better seismic resistance because many of these constructions were left unscathed, as mentioned by Frei Manuel da Epifania (AA. VV 2000). In fact, the overhanging houses differed substantially from other stone medieval structures (the two above mentioned construction typologies, with low- and high-quality masonry) due to the lightness and deformability of the timber skeleton so as to support the upper stories and the connections between the timber frame of the main facade and the floor structure. In addition, the overhang could protect the ground floor from exposure to atmospheric agents (Appleton 2008; Pereira and Buarque 1995; Pinho 2000).

3. Brief description of the overhanging dwellings in Lisbon

3.1. Architectural features

The so-called *casas de andares em ressalto* generally occupied long and narrow lots (gothic lot). Facades with one or two overhangs on one side are thus small, ranging from three to seven meters wide. On the other hand, the overhangs at the corner of the street rise in two directions (Oliveira and Galhano 1992).

The building components corresponded to multiples of the current units (i.e., *palmo* equal to 22 cm and *vara* equal to 110 cm) (Carita 1994). There was a proportional order between the building height and the size of the wooden components (Carita 1999).

The plan was organized for one dwelling per floor and shops on the ground floor, connected by a steep staircase (0.60 m wide), the so-called *de tiro*, supported by side walls in stone masonry (Figure 3). If the depth of the lot was insufficient, the vertical access bounded the perimeter of the house (L-shaped). The average inter-story was equal to approximately 2.20 m (Santos et al. 1990).

To the rear, a small and open area (*logradouro*) was generally intended for domestic activities and was fundamental for ventilation. No corridors and sanitary installations were included. The openings were



Figure 3. Staircases in Lisbon medieval dwellings: (a) photo of case study of *Rua de Castelo Picão* nr 20-22; (b) photo of case study of *Largo de Chafariz* nr 35-37. © S. Stellacci. Reproduced by permission of S. Stellacci. Permission to reuse must be obtained from the rightsholder.

protected by timber planks or grilles (windows were introduced after the 1755 earthquake) (Mascarenhas 2004; Santos et al. 1990).

3.2. Material and mechanical characterizations

The ground floor and the foundations were generally made of mixed stone and brick. The wall was very thick (from 0.60–0.70 m), with irregular blocks of limestone and massive ceramic bricks (0.125 m x 0.25 m x 0.03 m), clay with lime as binding, and plastering lime mortars (Santos et al. 1990) with clayish sand with an aggregate size of 0.15–4.80 mm (Pinho 2000). Regular laid bricks were used to fill the gaps between the masonry stone blocks. Other uses of ceramic bricks included the construction of safety arches above the openings, cornices, and several architectural details (Santos et al. 1990) (Figure 4).

Upper facades had an overhang ranging from 0.20–0.90 m with significantly thinner walls (from 0.15–0.20 m), combining the flexibility of wood and the compressive strength of stone and bricks. The timber frame guaranteed the shear restating system of the building. Mortar made with lime and sand was generally used as filling material and provided the masonry a monolithic behavior even under earthquake action. Timber planks originally protected the overhanging jetties from atmospheric agents.

Although *Castanea Sativa* was a commonly used species of wood, other species are found due to the frequent replacement of the timber components over the centuries. As evidence of this, the samples taken from floor beams in the first case study analyzed below were *Pinus Pinaster Ait.*, and are not thought to belong to the original construction period. In fact, the original round section beams supporting the timber floor were made of *Pinus sylvestris* and *Castanea Sativa* (Appleton 1991). The information regarding wood species remains incomplete and should be the topic of future research.

The interior area was subdivided by half-timbered walls (*frontais*) and by the so-called *tabiques* timber walls (from 0.10– 0.15 m) (Santos et al. 1990), made with vertical timber boards or diagonally crossed (0.10 m in thickness) and covered by lime and clay plaster (Appleton 1991). Unlike in other European countries, the traditional timber walls of the upper floors were always protected by plaster (Santos et al. 1990), in a three-layer scheme, in order to regularize and protect the surface (*emboco, reboco, esboço*), and by a finishing layer (*barramento)* on which the painting was applied. Mineral and organic additives were often used to improve water resistance and adhesive properties. In both the internal and the external surfaces, the mortar layers were produced with a decreasing binder-to-aggregate ratio to promote a progressive deformability and increased porosity from the inner to the superficial layers. The surface layers were prepared with lime paste and fine stone particles. The final layer was ochre or pink, obtained from iron oxide and natural blue pigments, or with a base of white lime and additives made from tallow (vegetable or animal fat). These mortars exhibited high water solubility, low shrinkage, sizable adhesion to the substrate, low mechanical resistance, adequate porosity, and good workability. The typical volumetric binder-aggregate ratio was 1:3 (Appleton 2003).

Several carvings leaving wood chips projecting from the surface, or protruding nail heads, enhanced the adhesion of the mortars to the wooden base. The same devices were later adopted in the *Pombalino* system.



Figure 4. Overhanging dwelling in *Rua Achada* nr 23-25, Lisbon: (a) photo by S. Stellacci; (b-c) hypothetical elevation and section. © S. Stellacci. Reproduced by permission of S. Stellacci. Permission to reuse must be obtained from the rightsholder.

4. Comparative analysis: overhanging dwellings versus *Pombalino* buildings

Traditional mixed timber-masonry structures embody the key principles of decreased thickness and inertial mass up to the height. These construction principles were systematized during Lisbon's reconstruction with the aim of improving the overall behavior of the building stock.

In the timber load-bearing structure built before and after the earthquake, the interior infill skeleton and the timber floors are linked together by means of carpentry or nailed joints and act in an integrated and homogeneous way (Santos et al. 1990). The main difference between these systems lies in a number of construction improvements to the regularity, modularity, and accuracy of details (Mascarenhas 2004; Penn, Wild, and Mascarenhas 1996) that, in turn, give the *Pombalino* system greater structural redundancy.

This comparison will be discussed by analyzing: (i) the building context; (ii) the timber framework and type of infill; and (iii) the floor structure.

4.1. Building context

The medieval tissue was compact and overhanging houses were included in blocks of overlapped and not homogeneous buildings, adulterated over the centuries. The main features of this typological group (e.g., location, configuration, and orientation) depend on the diachronic development of the urban settlement. The main medieval road, *Rua Nova dos Mercadores*, was directed parallel to the River Tagus.

The medieval overhanging dwellings, as well as the other vernacular structures, were influenced by the irregular morphology of the territory, by its specific use (residential, craft shops, and mixed) and by the poor socio-economic class of inhabitants. Despite the original satisfactory seismic response (tested by the 1755 earthquake), structural degradation due to neglect or intrusive transformations over the centuries compromised their safety level. The uneven behavior of the current buildings was also due to the subsoil and the isolated rehabilitation works (Appleton 2001, 2008).

Conversely, the downtown city was constructed in a regular and homogeneous urban grid, seeking a proportion between the height and size of the quarter (2/3 depth and length) (Mascarenhas 2004). Unlike the main medieval road, *Pombalino* main axis, *Rua Augusta*, was orthogonal to the estuary basin (Figure 2). *Pombalino* building stock was conceived in order to improve the stability and achieve a *block effect*, where the response of a building would also depend on the other connected buildings of the block (Cóias e Silva et al., 2001). However, the recent adulterations (e.g., extra floors, demolition of the internal structure and enlargement of the openings) weakened its structural performance (Cóias 2007; Mascarenhas 2004).

4.2. Timber framework and type of infill

The comparison of the half-timbered wall focuses on the external front of medieval houses *versus* the internal skeleton of *Pombalino* buildings.

In the examples of medieval Lisbon (and also of Guimarães among others), the bracing elements of the external overhang walls were irregular and the vertical continuity of the posts within a wall and between floors was not guaranteed (Santos et al. 1990, Figure 5). There was no systematic type of connection between the overhanging walls, the interior walls, and the side walls (Figure 5).

Unlike the overhanging houses, the *Pombalino* system is characterized by the execution of the timber-framed walls as an internal and continuous framework, the so-called *gaiola* (*cage*), with the systematic use of St. Andrew's crosses, which provided bracing elements to the structure, guaranteeing a less fragile and more ductile behavior, as has been observed in various experimental analysis carried out on such walls (Gonçalves et al. 2012; Meireles et al. 2012; Poletti 2013). The regular bracing components present in the frontal walls of *Pombalino* buildings and the use of timber-framed walls guaranteed that the system had greater shear resistance, with timber-framed walls acting as efficient shear walls (Meireles et al. 2012; Poletti and Vasconcelos 2015). The external *Pombalino* walls have a more simplified structure than the internal framework (Mascarenhas 2004). In fact, the latter are made of mixed masonry and a nailed wooden timber frame close to the internal face. The exterior walls present a few timber elements that are linked to the timber floors and the half-timbered walls by means of metal ties, which should to some extent prevent an early out-of-plane failure.

Nevertheless, a peculiarity of this type of building is that, if there is an earthquake, the heavy exterior masonry walls may fall down but the timber frame should remain standing and thus the collapse of the timber floors is avoided (Mascarenhas 2004; Simões et al. 2015).

The concept of allowing a partial collapse if a seismic event occurs is also common to other cultures; for example, in the timber-framed houses in Lefkas (Greece), the masonry walls on the ground floor could collapse and a secondary structural system consisting of timber posts would support the upper timber-framed stories (Vintzileou et al. 2007).



Figure 5. Examples of irregular bracing in a 17th century house in Guimarães. © E. Poletti. Reproduced by permission of E. Poletti. Permission to reuse must be obtained from the rightsholder.

To sum up, the *Pombalino* internal structure systematized the former traditional timber technique by: (i) a regular execution of Saint Andrew's crosses; (ii) the robustness and the regularity of the cross-section shape of its components, especially timber posts (*prumos*) and upright diagonals (*travessenhos*); (iii) a regular laying of the infill; (iv) the accuracy of the connections between the structural members (carving or nailing); and (v) a vertical alignment of the framework at every level.

In addition, it is noted that the opening size was reduced in the medieval buildings to avoid interrupting the timber framework in the overhanging facade (Oliveira and Galhano 1992; Santos et al. 1990). This constraint was overcome in *Pombalino* buildings by using multi-leaf masonry within the main facade, in order to assure the stability of openings without compromising considerably the overall mechanical resistance (Figure 6).

On the ground floor of the overhanging dwellings, the doorjambs were made of stone, supported by a brick arch (*arco de ressalva*) within the thickness of the stone masonry (Santos et al. 1990). On the upper floors, the windows were small so as not to interrupt the timber-framed wall and the doorjambs in coated wood to decrease the weight. On the other hand, in the *Pombalino* system the salient elements and the timber facade were forbidden (França 1987; Mascarenhas 2004) and the doorjambs were made of Lioz limestone.

The infill of the timber framework plays a key role as it provides additional strength, stiffness, and ductility to the walls and its characteristics greatly influences the walls' response. Traditionally, rubble or stone masonry was used for infill, but sometimes also mud and hay (Cóias 2007; Mascarenhas 2004). In a few cases, laths and plaster were applied, in a similar way to the wattle and daub used in northern countries (Mascarenhas 2004). A stronger infill gave the walls greater stiffness, as it would have a confining effect on the connections. Moreover, lath and plaster provided additional ductility, as it constituted a more flexible type of infill and it would improve the displacement capacity of the walls (Poletti and Vasconcelos 2015). The on-site analysis revealed that the infill of medieval houses was extremely irregular when compared to the *Pombalino* frames, in part due to the irregular geometry of the framework (Figure 5).

4.3. Floor structure

In both systems, the floor structure was mono-directional and laid perpendicular to the main facade and thus the wall structure was blocked by floor beams (Penn, Wild, and Mascarenhas 1996; Santos et al. 1990). In the *Pombalino* system, the floor beams rest on a continuous beam (*frechal*) in the wall thickness thus allowing a better distribution of the loads of the floor beams. In the medieval overhanging houses, the timber beams rest on a continuous beam jutting out from the external wall. In some cases, the overhanging facade is held up by consoles in stone in order to increase the dimension and the quality of the support (e.g., in *Rua da Regueira* nr 37, Lisbon).

Compared to the medieval floor structures, the *Pombalino* system is characterized by: (i) selected qualities of the timber components; (ii) regular sections and

constant spacing of beams; (iii) continuous beams for the entire depth of the building; (iv) use of long plates of ironwork (*ferrolhos*) fixed on the top surface of the beams or on the lateral side to masonry walls to improve the floor´s stiffness and the stability of the vertical frames out of plan; (v) a connection between the orthogonal walls through the vertical posts common to two walls; and (vi) the connection between floors and walls (e.g., nailing of the floor beams to specific timber elements embedded in the masonry walls).

It is worth noting that some structural aspects nevertheless remained unchanged in the latter system: the joists are oriented perpendicular to the front (even when it would be cheaper in the opposite direction) and are suitably fixed together in the transverse direction through wood billets (Cóias 2007).

In both cases, traditional carpentry joints were used, namely half-lap or dovetail joints, adopting also pegs or nails. These types of joint have shown good seismic behavior with a great dissipative capacity. Pull-out and in-plane cyclic tests performed on half-lap joints used for traditional timber-framed walls have shown the good deformational capacity of the joint, together with the great dissipative capacity that is then exploited by the walls (Poletti 2013). The seismic-performance of carpentry joints is also confirmed for other types of joints. Various studies related to many timber roof structures are available on bird's mouth connections, pointing out the good moment-resisting capacity of the connections (Branco, Piazza, and Cruz 2011; Parisi and Piazza 2000, 2002). For seismic-resistant purposes, strengthening performed with metal devices was essential to increase the joint's ductility and viscous damping. Compression and tension tests performed on dovetail joints with and without dowel confirm the good capacity of the joint (Sobra et al. 2015).

In *Pombalino* buildings, particular care was given to the connections between horizontal and vertical components in order to avoid local weaknesses and guarantee the building's good seismic performance by means of pre-carved posts and nailing posts (on the external side) to beams embedded into the external facade. In many cases, iron ties were also used (Mascarenhas 2004).

5. Survey of Lisbon's overhanging dwellings

5.1. Localization of the overhanging dwellings and degree of authenticity

The typological analysis attempts to assess characteristics that are common to every component of the same chronotype group (e.g., overhanging houses), in terms of spatial/distributive and architectural solutions (Santos et al. 1990). This method is fundamental to decode the still standing built heritage in order to ensure the basis for appropriate rehabilitation and retrofitting processes.

The still-standing medieval houses are implanted in the traditional parishes of *Alfama, Mouraria*, and *Castelo*, a dense urban tissue on the steep slope of S. Jorge Castle (Appleton 2008; Penn, Wild, and Mascarenhas 1996). This area is currently under strong pressure from the real estate market. The soil properties vary: some have a high seismic vulnerability (predominantly consolidated sandy, incoherent compact soil) and others a medium degree of seismic vulnerability (consolidated clay, low resistance soil, soft rocks) (CML 2006).

The main objective of this inventory by typological analysis is to identify the structural and architectural authenticity of the thirty-three overhanging dwellings (isolated and as a group of buildings) listed by Lisbon Municipality (CML 2010).

The evaluation of authenticity according to the categories proposed in this article (Table 1) is based on Municipal archival data and physical evidence. This latter is used when municipal data is missing (AML, Dossiers nr 20796, nr 20857, nr 8956); the degree of authenticity is therefore assessed on the basis of physical evidence, such as visibility of the wall structure and specific pathologies (Figure 4).

In the overhanging examples, barely 15% maintain their structural and/or architectural authenticity (Table 2). In addition, two examples emerged of structural and architectural authenticity (state of total authenticity in *Rua Achada* nr 23–25; partial in *Rua da Rigueira* nr 1-1A) in urgent need of strengthening measures.

5.2. Causes of adulteration and degradation

These medieval houses have been subjected to considerable alterations as a consequence of fires, earthquakes, legislative decrees, the needs of their inhabitants, and so on. The main causes of the replacement of the half-timbered walls over the centuries were the above-mentioned decree issued by King D. Manuel I ordering the substitution of the timber framework with brick walls (CML, 1957), natural causes (earthquakes of 1755 and 1969) and the advent of concrete in the early 20th century.

Among the many adulterations dating back to the late 18th century, the introduction of a window in the external facade and changes in the internal layout (Appleton 2008) are very frequent in the medieval houses.

The archival data in most cases reports pathologies caused by a lack of maintenance and the degradation of

Table 1. Degrees of authenticity of the overhanging dwellings, as proposed in this research.

Degree of Authenticy	(almost) Total	Partial	(almost) Naught
Structural features	i) Original (or rebuilt in 18th –19th C) external walls (overhanging half-timbered walls) ii) Original floor structure	i) Partial replacement of external walls and reinforcement of original structure ii) Partial replacement of floor structure	i) Replacement by concrete structure ii) Replacement of floor structure, new staircase and elevator shaft
Morphological/typological features	i) Maintenance of building environment ii) Original volumetric composition iii) Original layout with some functional adjustment (i.e., timely interventions, plumbing and sanitary facilities)	i) Few changes of building environment ii) Original volumetric composition iii) Several interventions (i.e., partial or limited demolitions, internal arrangements)	i) Several changes of building environment ii) Few changes in volumetric composition iii) Changes of original distribution (i.e., demolition of internal walls, new access system)
Finishing and architectural details	i) Original facade ii) Permanence of architectural features (i.e., railing, chimney, door jambs, handrail, ceramic panel) iii) Compatible plaster in material composition and colour	i) Alteration of openings on the ground floor ii) Loss of few distinctive features iii) Plaster with medium/high material compatibility and low chromatic compatibility (or vice versa)	i) Alteration of openings on entire facade ii) Loss of many distinctive features iii) Non-compatible plaster in composition and color

materials, especially in the overhanging volumes and the roof. Detached plaster, rotten timber structure and water infiltration from the roof are the most cited pathologies (AML, Dossiers nr 21940, nr 34998, nr 8956). In some cases, other causes of structural weakness are also attributed to the 1969 earthquake (AML, Dossier nr 21285, nr 32210) or the construction of the underground public car park in *Praça Martim Moniz* in 1981. In particular, despite the limited range of the car park's impact (10.00 m), it affected a traditional block of overhanging buildings (AML, Dossier nr 13444).

On the other hand, considerable efforts were made from the 1970s to improve housing conditions and structural performance through a public campaign for social and urban recovery. A technical office, set up in 1985/86 and reorganized in 1990/1, was installed in *Alfama* with several duties: inventory, sociological survey, and urban renovation programmes. Furthermore, a funding program (RECRIA) was established in the late 1980s through which grants were awarded for up to 65% of the total cost of works.

The Lisbon archival dataset shows that high demand led to a separation of dwelling units from the 1960s, despite the poor living conditions and limited space (e.g., AML, Dossiers nr 11051, nr 19343, nr 20972, nr 21285, nr 21582, nr 21713, nr 21940, nr 3217).

6. Case studies in Lisbon

6.1. Continuities and dissonances

In the framework of this research, continuities mean the survival of the main architectural features, as well as the internal and external configuration.

Dissonances refer to adulterations caused by the introduction of elements that did not match the original construction, the local architectural lexicon or the historical stratifications. The replacement of the traditional structures (e.g., half-timbered walls, timber floor and roof), architectural details and traditional finishing (e.g., balconies, window frame, plaster) with modern construction systems (e.g., mixed structure of reinforced concrete and steel) should be evaluated as dissonances given that these practices could invalidate the buildings' traditional value. On the other hand, alterations like mergers of plots, introduction of *Pombalino* windows or dormer window and few functional adjustments, may not be considered dissonances because they are part of the building's history and represent adaptations needed for basic living requirements (ICOMOS 2003). However, it is necessary to record the original state and the stages of rehabilitation process (ICOMOS 1996).

In most of the cases analyzed, the original volumetric configuration, affecting the urban environment and the citizen memory, was preserved. On the other hand, only a few of the original features remain: wooden painted planks, white double-hung windows, narrow balconies and votive panels.

Additionally, there are frequent dissonant elements within the later intrusive refurbishments (replacement of infill frame walls with brick and reinforced concrete structure, alteration of the position of the openings on the main facade, profound typological changes).

Continuities and dissonances are discussed below in three case studies, selected predominantly due to the availability of dataset, their central location and outstanding features such as expressions of local craftsmanship (Figure 7a).

Table 2. Lisbon's overhanging dwellings divided for degree of authenticity and state of conservation.

Degree of Structural Authenticy	(almost) Total	Partial	(almost) Naught
Case studies	***Rua do Benformoso, 101–103***	*Rua da Galé, 13–15**	***Rua da Guia, 1/7****
	Rua Achada, 23–25	*Rua das Farinhas, 32–34*	*Largo de S. Miguel, 5, Rua de S. Miguel 18–20*
	Rua dos Cegos, 20–22	*Rua da Regueira, 1-1A*	*Rua do Vigário, 2–4, Rua dos Remédios, 121**
	Largo do Chafariz, 32–33-35–37	*Escadinhas dos Remédios, 5–7*	*Beco da Cardosa, 10*
	Calçadinha de S. Estêvão, 1, Rua dos Remédios, 25–27	*Rua do Castelo Picão, 20–22, Beco da Cardosa, n.36**	*Pátio da Cruz, 3–4*
		Rua de S. Miguel, 61–63	*Beco das Canas, 3–5*
		Largo do Chafariz de Dentro, 22–23	*Rua de S. Miguel, 25*
		Calçada de S. Vicente, 15–17	*Rua do Espírito Santo 2, Rua de S. Cruz do Castelo, 15*
		Escadinhas de S. Estêvão, 1–5, Rua dos Remédios 41	***Beco de S. Miguel, 17***
		Rua do Chapelão, 2–4-6–8, Rua da Mouraria, 80–82-86–90	*Rua dos Remedios, 63–65, Beco Maria Guerra, 2*
		Rua da Regueira, 37, Beco das Cruzes,1	*Travessa de S. Miguel, 9–11*
		Rua João do Outeiro, 9–11	*Largo do Chanceler, 3-3A*
		Calçadinha de São Miguel, 38–40, Rua do Capel Picâo, 6	*Beco das Barrelas, 2–4*
			Beco da Formosa, Pátio do Prior
			Rua do Benformoso, 80–84-88–90
	(almost) TOTAL	**PARTIAL**	**(almost) NAUGHT**
	15%	41%	44%

STATE OF CONSERVATION	GOOD	MEDIUM	MEDIOCRE
Case studies	*Rua dos Cegos, 20–22*	*Largo de S. Miguel, 5, Rua S.Miguel 18–20*	***Rua do Benformoso, 101–103***
	Rua da Guia, 1/7	*Rua das Farinhas, 32–34*	*Rua Achada, 23–25*
	Largo de Chafariz, 32–33-35–37	*Beco das Canas, 3–5*	*Rua da Regueira, 1-1A*
	Largo do Chafariz de Dentro, 22–23	*Escadinhas de S. Estêvão, 1–5, Rua dos Remédios, 41*	*Pátio da Cruz, 3–4*
	Calçada de S. Vicente, 15–17	*Beco da Formosa, Pátio do Prior*	
	Rua de S. Miguel, 25	*Rua da Regueira,37, Beco das Cruzes, n.1*	
	Rua de S. Miguel, 61–63	*Beco da Cardosa, 10*	
	Rua dos Remedios, 63–65, Beco Maria Guerra, 2	***Beco de S. Miguel, 17***	
	Travessa de S. Miguel, 9–11	*Rua do Vigário, 2–4, Rua dos Remédios, 121**	
	Largo do Chanceler, 3-3A	*Rua da Galé, 13–15**	
	Rua João do Outeiro, 9–11	*Escadinhas dos Remédios, 5–7*	
	Beco das Barrelas, 2–4	*Rua de Castelo Picão, 20–22, Beco da Cardosa, n.36**	
	Calçadinha de S. Miguel, 38–40, Rua do Capel Picâo, 6		
	Rua do Espírito Santo 2, R. de S. Cruz do Castelo, 15		
	Rua do Chapelão, 2–4-6–8, Rua da Mouraria, 80–82-86–90		
	Calçadinha de S. Estêvão, 1, Rua dos Remédios, 25–27		
	Rua do Benformoso, 80–84-88–90		
	(almost) TOTAL	**PARTIAL**	**(almost) NAUGHT**
	49%	39%	2%

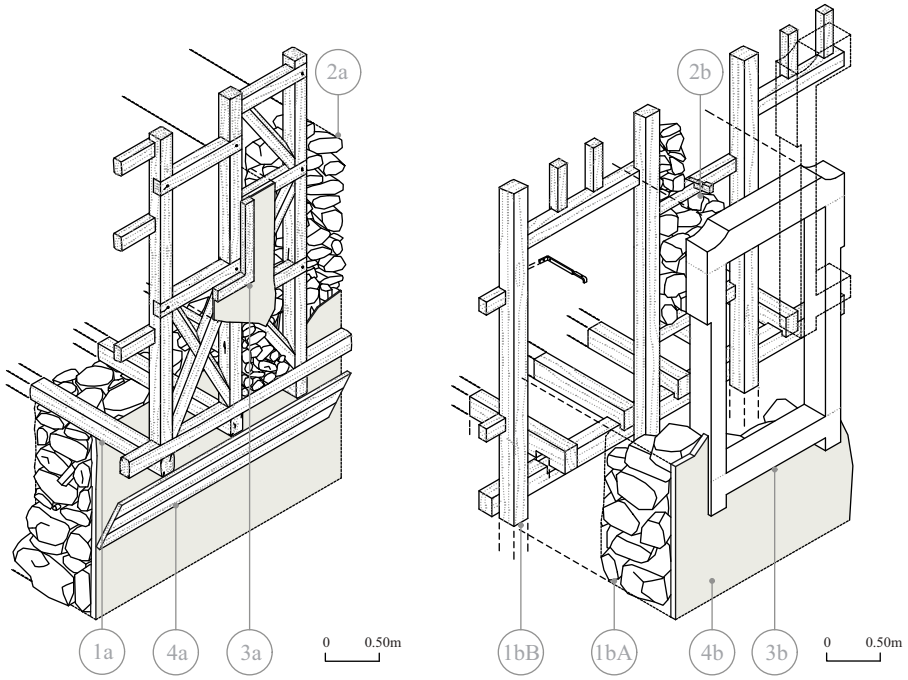
* financed by funding programmes (RECRIA or REHABITA); In bold = case studies.

6.2. Case study of Beco São Miguel nr 17

This case is a bilateral overhanging structure on three storeys set on a square plan, close to *São Miguel* Church. Over the centuries, there have been significant alterations to the context, as shown in Figure 8.

Following a coercive process carried out by Lisbon Municipality in 1941, refurbishment works were undertaken. However, the following recommendations by the Technical Supervisor of Lisbon Municipality were disregarded: the alignment of openings, the use of reinforced concrete instead of iron bars to support the balcony and several finishes such as the ceramic tiles in one of the facades. In fact, the structural authenticity was completely lost (AML, Dossier nr 21582).

During the structural strengthening in 1941, the half-timbered walls on the upper floors were replaced with a



1a. overhanging facade: a half-timbered frame laying on floor structure
2a. limestone blocks and ceramic bricks
3a. timber door jamb (or plaster)
4a. timber planks to protect the overhang

OVERHANGING DWELLING
external wall structure

1b. flat facade: a mixed masonry (A) and nailed wooden timber frame (B)
2b. rubble stone infill
3b. Lioz limestone door jamb
4b. no external timber structure

***POMBALINO* BUILDING**
external wall structure

Figure 6. Axonometric view of the external walls: overhanging facade versus *Pombalino* facade. © S. Stellacci. Reproduced by permission of S. Stellaci. Permission to reuse must be obtained from the rightsholder.

reinforced concrete structure, hollow bricks and cement mortar (Figure 9). The cantilevered balconies represent a local declination of the Islamic *muxarabi* (Carita 1999); however, historical photographs from Lisbon Municipal Archive reveal that the timber balconies are recent. The dark pink facade and the absence of timber planks to protect the overhangs are additional dissonant elements in need of correction.

6.3. Case study of Rua do Benformoso nr 101–103

This double-jetted dwelling is located in a street that was a principal access to the old city, trade and procession routes, notably until the construction of *Rua da Palma* nearby in 1862.

As a result of the public inspection of 1919, Lisbon Municipality issued an injunction to demolish this entire building due to structural problems on the upper floors and on the rear facade (AML, Dossier nr 33695); however, this order was not complied with. The still-standing house is one third of the original building (Figure 10a), with shops on the ground floor and housing on the upper floors. In fact, two-thirds of the original block was demolished in 1928 with Municipal approval (AML, Dossier nr 15936). The existing building is implanted on a rectangular lot and is listed as a building of public interest (Decree Law nr 181/70).

This case is characterized by the permanence of the main original structural and architectural features, except for the ground floor where alterations were made to the composition of the facade and, to some extent, to the interior area due to the installation of a lift in 1985 (AML, Dossier nr 33695). Another window was recently introduced on the ground floor without municipal approval, as shown by the photographic comparison (Pereira and Buarque 1995).

The shaping of the curved and painted doorjamb is a unique example in Lisbon (Figure 10); the typical 17th century railing, the so-called *varão e nó* (literally *bar and node*) is also a local element.

As shown by the historical photographs, the current plaster (mustard color replacing white background and

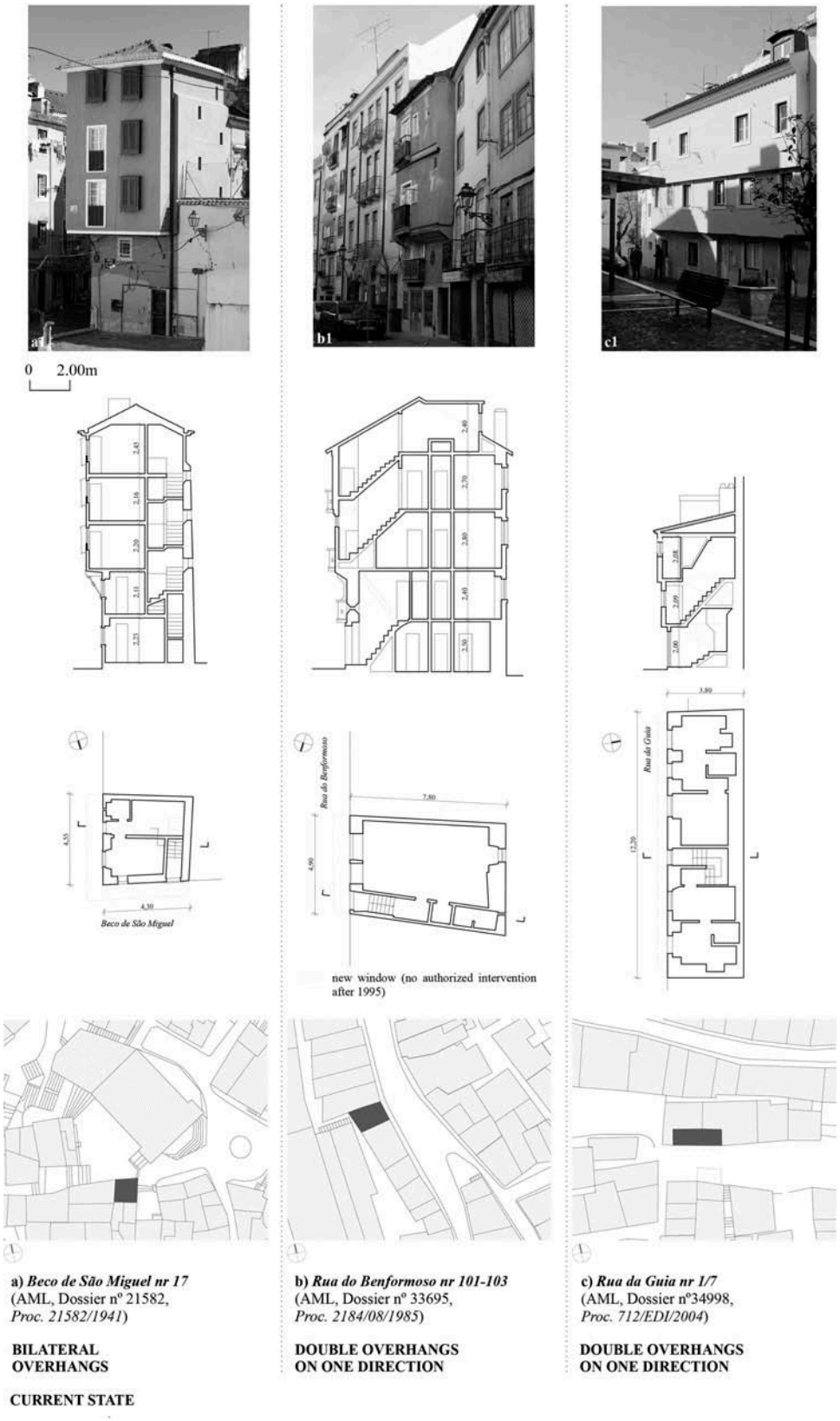


Figure 7. Three case studies in Lisbon: (a) in *Beco São* Miguel nr 17; (b) in Rua do Benformoso nr 101-103; (c) in *Rua da Guia* nr 1/7. drawing © S. Stellacci; photos © AML (Arquivo Municipal de Lisboa). Reproduced by permission of S. Stellacci and AML. Permission to reuse must be obtained from the rightsholders.



Figure 8. Case study of *Beco São Miguel* nr 17, Lisbon: (a) photo by unidentified author (1889–1908) and current photo; (b) elevations; (c) axonometric view of the current state. Drawings © S. Stellacci; photos © AML (Arquivo Municipal de Lisboa). Reproduced by permission of S. Stellaci and AML. Permission to reuse must be obtained from the rightsholders.

dark strips in the corners) and the recent openings on the ground floor represent the main dissonances that could be corrected.

6.4. Case study of Rua da Guia nr 1/7

The double jutting house dates probably from the 16th century and was altered in the 17th century (Appleton 1991). This dwelling is set on a rectangular lot close to a well-known popular square, *Largo da Severa*. Originally conceived as a multi-family house with two apartments per floor, this example is characterized by a bi-axial symmetric functional scheme (Figure 7c).

During Lisbon's reconstruction, the same building type was largely employed through four main typological variants (so-called *right-left*) (Mascarenhas 2004). The distribution scheme of this case is rare in Lisbon's medieval houses; the common solution in the Middle

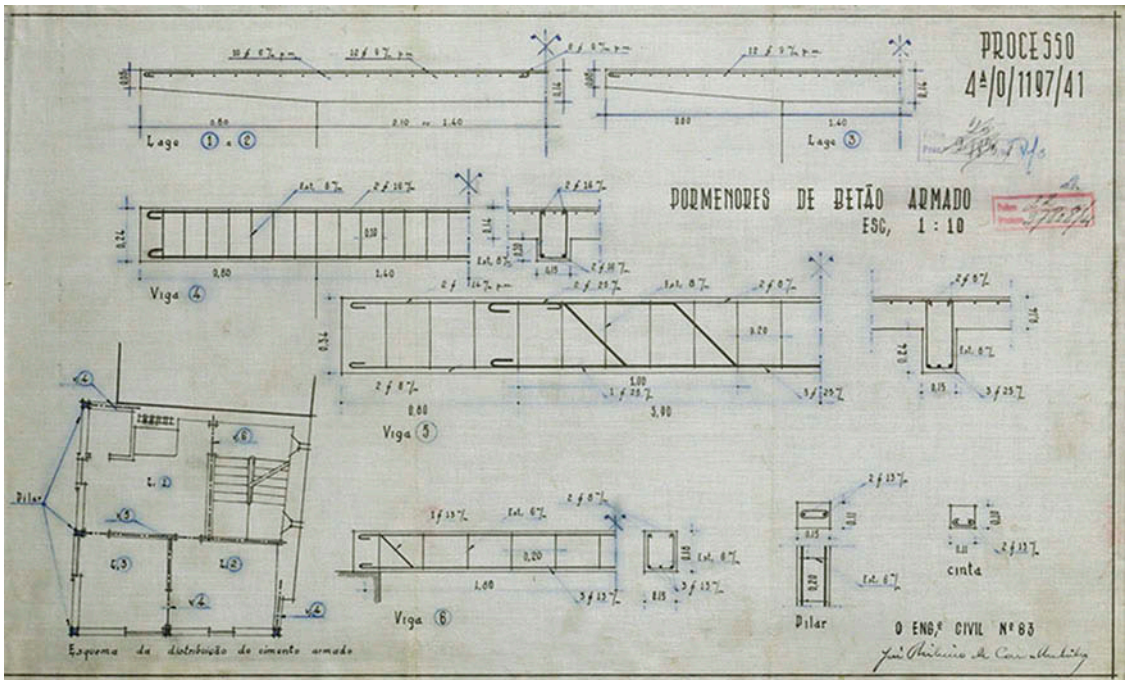


Figure 9. Case study of *Beco São Miguel* nr 17, Lisbon: project for replacement of the timber-framed walls with reinforced concrete structure (1941) (AML, Dossier nr 21582). © AML (Arquivo Municipal de Lisboa). Reproduced by permission of AML. Permission to reuse must be obtained from the rightsholder.

Ages relied on asymmetric access in one lateral edge of the main facade (Santos et al. 1990).

The original construction probably consisted of one floor; the upper floors with external half-timber-framed walls were executed during a second construction phase in the 18th century. Plumbing and sanitary facilities were also added in this period (Appleton 1991; AML, Dossier nr 34998, vols. 1–2).

The vertical continuity of the internal walls that supported the staircase suggests a strong influence of the load bearing capacity, when compared to that of the other walls (*tabiques*). However, the *tabiques* provided an overall interlocking of the building under seismic load perpendicularly to the main facade (Appleton 1991).

This building was altered without municipal authorization in 1987. Works included the introduction of concrete pilasters to support the overhangs and the replacement of half-timbered walls with a concrete structure and hollow bricks (AML, Dossier nr 34998, vol.2). These abusive works were coercively and belatedly interrupted. Lisbon Municipality was initially interested in expropriating the building and refurbishing it as a Portuguese guitar school (Appleton 1991); however, the project was unfortunately discarded.

The original layout of the main facade was compromised due to the alteration of openings, the loss of stone doorjambs and the heterogeneous external frames (guillotine windows in the 18th century)(Appleton 1991). In addition, the orange-pinked plaster represents a dissonance that needs to be resolved (Figure 11).

7. Principles for safeguarding purposes

Since the *Venice Charter* (1964), the assessment of the structural authenticity has represented a fundamental requirement for the built heritage. It is a key objective of refurbishment policies and for the listing of heritage (ICOMOS 2003; Nezhad, Eshrati, and Eshrati 2015). The significance of the historical buildings depends on preserving the coherence of the *construction processes*, the *material dimension* and the *expressive solution* (Zancheti, Flaviana, and Rosane 2009).

The rehabilitation of the built heritage demands careful analysis and low intrusive intervention: *the integrity of all its components* (ICOMOS 2003) in terms of architectural and structural features should be preserved.

In medieval dwellings, the construction phases depended on the successive assembly of elements and the aggregation process occurred by means of a vertical juxtaposition of elementary spaces. Construction by juxtaposition could be analyzed in reverse, in order to understand the techniques and structural principles and to preserve the components (Carocci 2001; Giuffrè 1997).

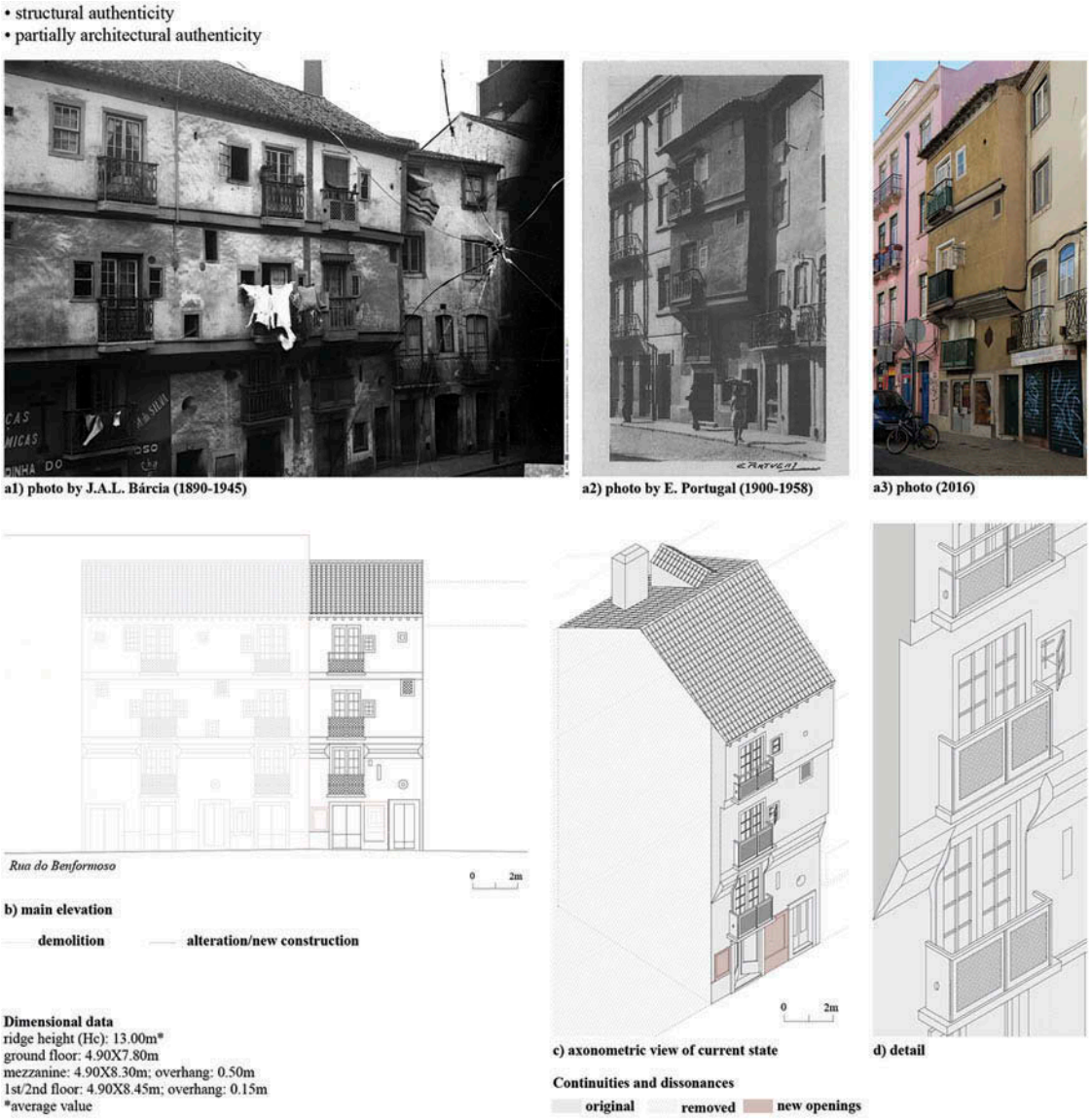


Figure 10. Case study of *Rua do Benformoso* nr 101–103, Lisbon: (a1) photo by José Artur Leitão Bárcia (1890–1945); (a2) photo by Eduardo Portugal (1900–1958) (Passos 1997); (b) main elevation, (c) axonometric view of current state; (d) detail. Drawings © S. Stellacci; photos © AML (Arquivo Municipal de Lisboa). Reproduced by permission of S. Stellacci and AML. Permission to reuse must be obtained from the rightsholder.

This preliminary inventory revealed a wide range of situations (Table 2); several structural, typological and architectural dissonances are irreversible. However, after the anamnesis, analysis of archival data and on-site survey, appropriate techniques could be used to restore the existing continuities and eliminate the observed weaknesses (intrinsic and added by inadequate alterations).

Based on the above premise, the principles for safeguarding this building typology relate to: (i) structural features; (ii) typological and morphological features; and (iii) finishes and architectural details (Table 1).

7.1. Structural features

A reliable structure (for strength and stability, serviceability, durability, and maintenance) requires a detailed on-site assessment, including the state of conservation of the timbers (pathology, residual cross section, and residual density) and the effectiveness of carpentry joints (Cruz et al. 2015).

Depending on the state of conservation, the reinforcement project entails establishing priorities as to whether dissonances/continuities should be preserved or discarded.

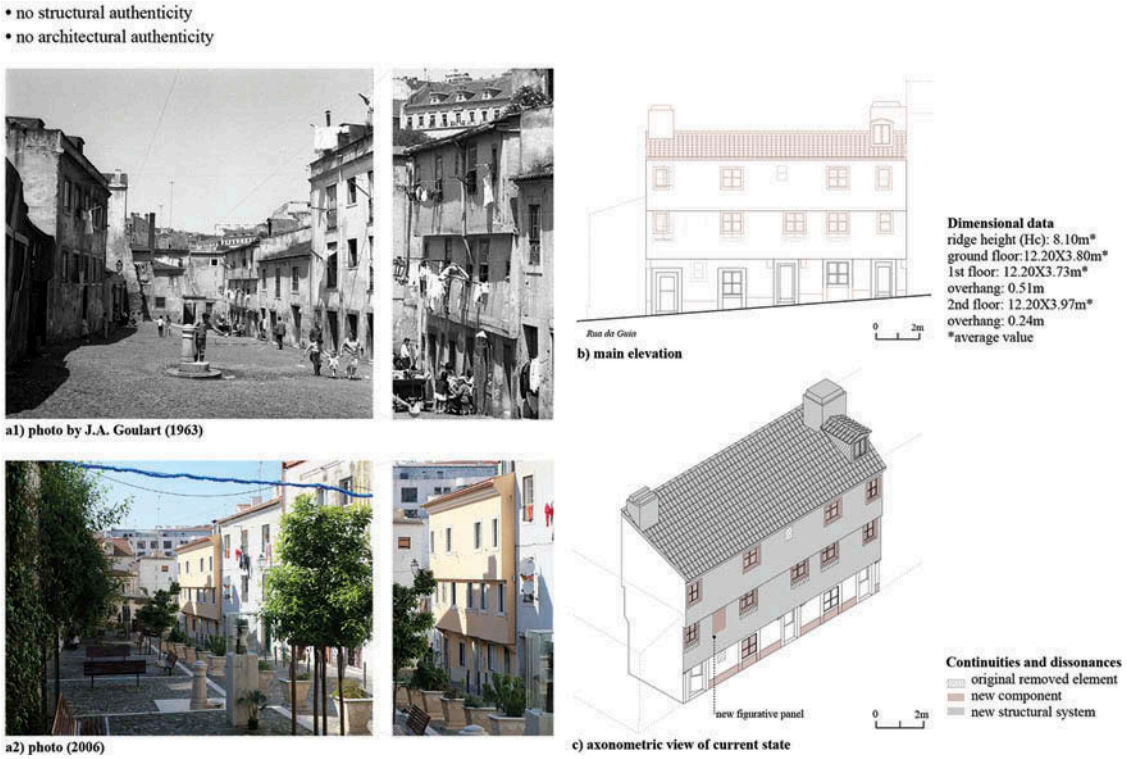


Figure 11. Case study in *Rua da Guia* nr 1/7, Lisbon: (a) photo by João Artur Goulart (1963) and current photo; (b) main elevation; (c) axonometric view of the current state. Drawings © S. Stellacci; photos © AML (Arquivo Municipal de Lisboa). Reproduced by permission of S. Stellaci and AML. Permission to reuse must be obtained from the rightsholder.

It is worth noting that the conservation and strengthening intervention should assure solutions that are compatible with the original structure, as highlighted in the literature (Cruz et al. 2015; Giuffrè 1997) and in current municipal regulations (CML 2010). It might include the replacement of damaged parts, and these should match the original component as closely as possible in material, design, species, grade, grain, dimensional stability, decay resistance, and environmental impacts. Traditional techniques and local materials are preferable, together with treated timber (e.g., Maritime Pine, Chestnut, or Nordic Pine in autoclave, with 12% water content), infill with lay bricks and hydraulic mortar (Appleton 2003).

On the other hand, reinforced render applied on both sides of the infill frame wall by means of mortar with low retraction or project reinforced shotcrete represent the current reinforcement techniques (e.g., AML, Dossier nr 21940), as described in the literature (Appleton 2003; Cóias 2007). The main drawback is that the grout has a cementitous base, which may cause local areas of stiffness, loss of ductility, and salt crystallization. Accordingly, the abovementioned technique could invalidate the specific properties of half-timbered walls (Gonçalves et al. 2012) and introduce pathologies due to physical, chemical and mechanical incompatibility.

Another aspect regards the compatibility of materials when using FRPs and resins (or even metal plates) to avoid inducing moisture concentration but which allow an exchange of humidity with the external environment to prevent an acceleration of decay (e.g., biotic attacks) (CNR-DT 201/2005). Additionally, chemical interactions between materials (strengthening component and timber as well as any treatment of timber) have to be considered. For example, fungicidal treatments (based on metal salts) could corrode steel components (Beckmann and Bowles 2004); the presence of tannic and acetic acid in oak could also cause corrosion in mild steel (Pender et al. 2012); the use of resins may cause condensation at the repair/timber interface and if used for an external repair they may be damaged by ultraviolet light (Pender et al. 2012).

When the state of conservation is such that the wall must be completely replaced, *compatibility is also a mechanical requirement*. The new structure can adapt to the original part of the structure if the contemporary operations respect the same strength and ductility of the original construction system (Carocci 2001; Giuffrè 1997).

7.2. Typological features

The original layout generally does not comply with national regulations and current standards. However, a flexible attitude should be taken to the requirements which should be adapted to the original construction; moreover, the minimum intervention criterion should be respected (ICOMOS 2003). It is advisable to avoid constructing (or enlarging) windows (or door-windows) especially in the main facade, introducing balconies and installing lifts.

7.3. Finishes and architectural details

As stated by Lisbon Municipality, the replacement of wooden frame, timber railing, and other traditional features of medieval buildings is forbidden (CML 2006). To comply with international guidelines (ICOMOS 2003) the removal of timber planks that protect the intrados of the overhang structure (e.g., first case study in *Beco São Miguel* nr 15) should also be forbidden. Periodic checks and maintenance operations should also be conducted due to the high level of decay of materials.

A detailed analysis of the original colors and material compositions should be mandatory. The facade-finishing color should be carefully assessed during regular on site survey. The appropriate colour should be decided on a case-by-case basis, supported by historical studies and avoiding uncritical solutions. As suggested by historical photos and an on-site chromatic analysis (mediated by the Natural Colour System-NCS) (Bissau 2012), the use of white or cream was common, with variations in the color of walls and the timber planks on the intrados of the overhanging volumes; the timber railing and *muxarabi* are traditionally dark green (literally *bottle green*).

The chromatic value of historical buildings is conceived as an *integral factor of the urban image* (Nery 1987) that could transmit the community's sense of belonging to the city.

8. Conclusions

The importance of safeguarding the medieval overhanging dwellings in Lisbon arises out of their symbolic and historical values, as well as of their construction system, which relies on the half-timbered wall. In a diachronic perspective, the timber-framed system represents a structural permanence within a seismically active area, namely in Lisbon.

The authors make a brief literature review and compare the structural systems used in medieval houses (e.g., overhanging dwellings) and in the *Pombalino* heritage (from the late 18th century) to underline the common construction principles that are often overlooked in the literature.

This research provides a survey of the still-standing medieval dwellings in Lisbon and their alterations over the centuries as shown in three case studies. For a number of reasons, barely 15% maintain their structural and/or architectural authenticity. However, the safeguard of the authenticity of this building typology should be the key-aim of policy strategies in order to keep the historical memory alive and to avoid intrusive rehabilitation and retrofitting solutions.

Future research suggestions could be focused on materials characterizations (e.g., wood species and mortars), on seismic assessment and on the retrofit of the examples that preserve their structural authenticity.

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Multi-criteria analysis of rehabilitation techniques for traditional timber frame walls in *Pombalino* buildings (Lisbon)

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ABSTRACT

This research aims to evaluate the intervention techniques currently adopted for the traditional timber frame wall, using a case study in downtown Lisbon.

Different rehabilitation solutions were identified and assessed through a multi-criteria decision analysis using dedicated software (M-Macbeth, *Measuring Attractiveness by a Categorical-Based Evaluation technique*).

Five evaluation criteria, i.e. material compatibility and permanence, structural reliability and authenticity, and visual-tactile appearance, were selected for this specific context. A multidisciplinary panel of experts in conservation science were consulted for defining the performance descriptors, evaluation levels, and weightings of these criteria.

Results show that Macbeth is a useful decision-aid capable of handling multiple outputs generated from qualitative expert judgments. Lastly, the predominance of five best-scoring interventions within three design-related scenarios is discussed.

1. Introduction

Building rehabilitation is a challenging task due to conflicting priorities pursued by multiple stakeholders, e.g. experts in conservation science, municipalities, owners, and contractors. In fact, safeguarding the authenticity of historic construction can conflict with the reliability of the rehabilitation work, budgetary constraints, and/or limitations imposed by the presence of occupants in the building.

When a variety of non-numerable and non-homogeneous criteria have to be taken into account for the selection of the best solution among several options, the decision-making process can be supported by *Multi-criteria Decision Analysis* (MCDA) [1,2]. However, although MCDA models can guarantee transparency and interactivity, these methods are rarely applied for questions regarding the preservation of historic structures, e.g. for the evaluation of cultural assets regarding solutions for their reuse [3] or for the assessment of different rehabilitation techniques.

This research presents a straightforward methodology to guide decision-making related to the preservation of timber-framed heritage in seismic-prone zones. The evaluation process is addressed by dedicated software (M-Macbeth, *Measuring Attractiveness by a Categorical-Based Evaluation Technique*) capable of handling multiple outputs generated from qualitative expert judgments [4,5]. This study investigates the opportunities offered by multi-criteria analysis in analysing a case study of buildings in downtown Lisbon (so-called *Pombalino* buildings).

Following its devastation by earthquake, fire, and tsunami in 1755, the downtown of Lisbon was reconstructed in situ by employing a set of advanced anti-seismic techniques [6,7]. This building stock covers an area of 23.5 ha and consists of 62 blocks and 430 building lots. Most of these buildings have remained unchanged in terms of number, volume, type of allotments, geometry of the facade as conceived in 1756–1758, while the degree of authenticity of each plots greatly varies. Many have undergone structural alterations; these include enlarging the openings at the groundfloor, adding extra floors, demolishing internal structures, and introducing new systems (lifts, staircases, overhanging structures to the rear). In few cases, major alterations of the entire volume were executed especially during the first decade of the 20th century.

The *Pombalino* structural system is based on a hyperstatic model composed of stone masonry external walls and a set of internal load-bearing timber frame walls that are connected to wooden floors by means of pre-carved posts or by nailing posts to beams embedded into the external facade (Fig. 1). The type of the connections greatly varies according to the dating of building execution. The most common joints used are the half-lap joints held in place by one or two nails, and less

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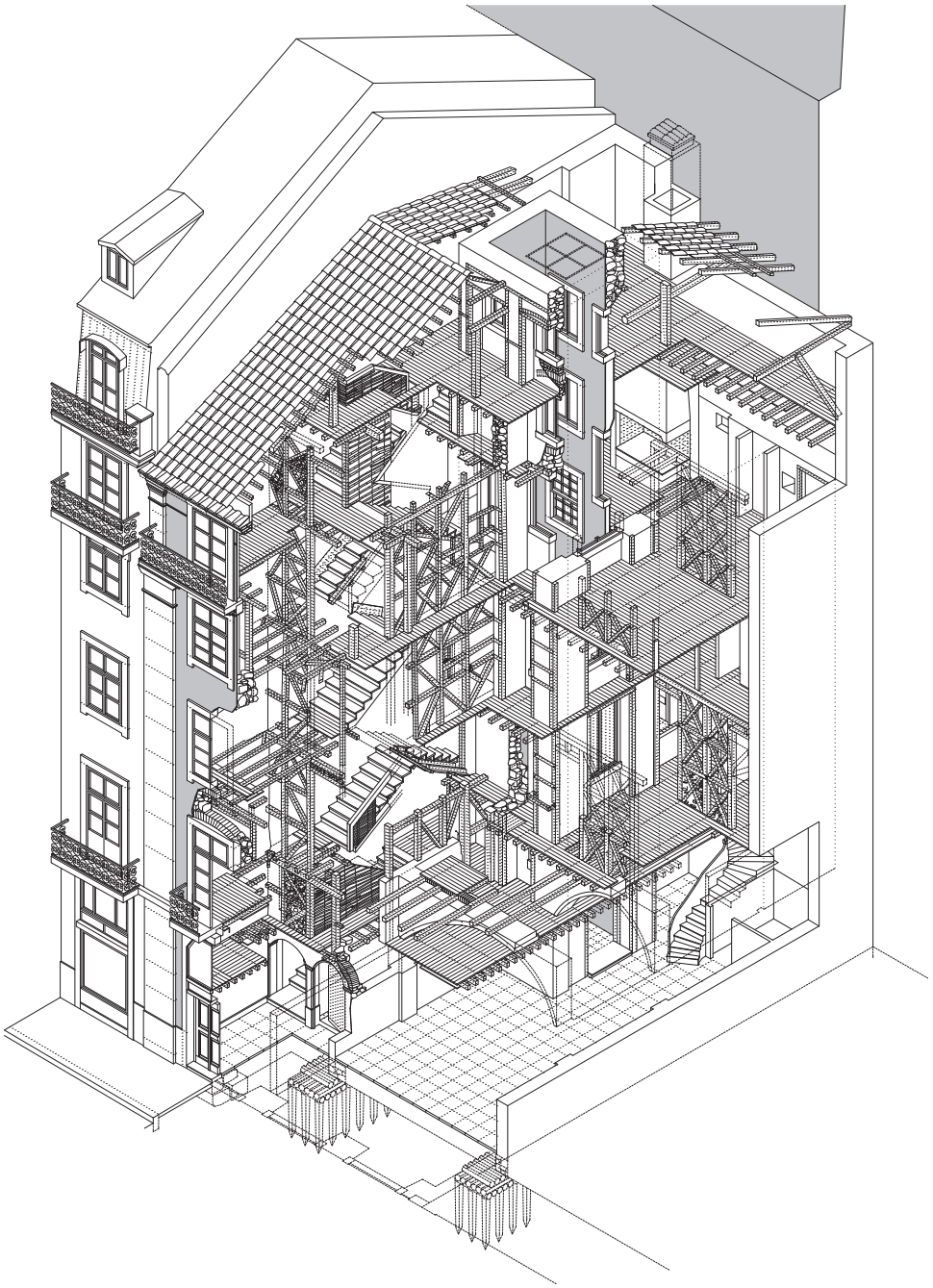

Fig. 1. Axonometric view of a *Pombalino* building in Lisbon (late18th century).

frequently, dovetail or mortise and tenon joints [8,9].

Above thick masonry pillars and stone vaulted ceilings of the ground floor, these three-dimensional timber frames above the first floor, reinforced by wooden cross-bracing components (10 × 10 cm or 10 × 8 cm), are designed to withstand seismic actions through the ductile behaviour of the joints and the satisfactory interlocking of each construction component (i.e. interaction of timber framework, joints, and infill) (Fig. 2). The ductility of the joints is directly related to the ability of the structure to deform nonlinearly without significant loss of strength, whereas the interlocking increases the maximum load and stiffness of the connection [10].

Pombalino construction, which was systematically employed from the late 18th century onwards in Lisbon's other districts as well, is remarkable evidence of a collective effort to reformulate time-tested local techniques (as testified by Medieval and Renaissance ordinary buildings in Portugal) and effect a comprehensive renewal of the city at urban, architectural, and structural levels [6,11].

Regardless of the significant value of these buildings and their central location, a remarkable decrease of occupancy was continuously registered from 1911 to 2011, with a loss of almost 90% of the inhabitants who initially lived in these houses [12]. This process of desertion was reflected in all the historical districts of the city, and it was followed by a considerable neglect of these constructions.

Countering this trend, significant real estate investment has been fostered in the last five years by the centrality of this building stock and new market demand linked mostly to the increase in tourist flow. Many of these buildings, previously empty or rented at very low prices, have been sold in recent years to private companies to accommodate restaurants and stored in the ground floor and hotels in the upper floors. The Portuguese government approved a special legal regime applicable from 2014 until 2020 devoted to the rehabilitation of these buildings with the aim of reducing the cost of interventions and fostering urban



Fig. 2. Internal view of a *Pombalino* building, *Rua dos Fanqueiros*, Lisbon (left); original and replaced cross-bracing components (right).

renewal. This building regulation exempts construction works from compliance with a number of requirements (e.g. habitability, accessibility, acoustic comfort, energy efficiency) and defines the minimum requirement of not reducing the structural and seismic safety of the existing structures [article 9, 13]. As recently underlined by the scientific community, the opportunity to set up an effective strategy for mitigation of seismic risk was therefore ignored by this government initiative [14].

Within this multifaceted historical context and in the absence of specific guidelines or technical rules, individual/private choices regarding intervention on historic buildings are frequently shortsighted. As shown in this work, interactive and collective deliberation is needed to support the decision makers (building owners or users).

The proposed methodology can also be used to assess interventions on a large number of load-bearing interior and/or exterior timber frame walls of traditional constructions in different geographical contexts [15–17].

2. Rehabilitation techniques of timber frame walls (TF)

2.1. Brief notes on the main principles of interventions on historical buildings

Essential requirements for interventions on traditional construction systems can be found in international guidelines and charters for the safeguarding of architectural heritage [18–20] and they can be summarized as follows:

(i) low intrusiveness and distinguishability;
(ii) physical, mechanical, and chemical compatibility with the original materials;
(iii) seismic upgrading by compliance with a reasonable equivalent safety.

Less intrusive interventions (i), which involve a minimization of loss of original material and the maintenance of the original structural model, should be privileged over any other solutions. The interventions should also fulfil the requirement of low visual impact. The replacement parts should integrate harmoniously with the whole in terms of material, design, species, grade, slope of grain, dimensional stability and decay resistance of the original components as closely as possible [19,21]. At the same time, the distinguishability of the intervention is guaranteed by the regularity of the replaced components in geometry, grade, type of assembly and by their macroscopic characteristics of the wooden members (e.g. knots, interfacial discontinuities, shake, splits) (Fig. 2, right).

Secondly, the concept of reversibility, following the recommendations of the Venice Charter [19], has today been supplanted by those of compatibility and retreatability (ii). In fact, the seismic retrofitting of mixed systems made of wooden components or the impregnation of a product within the porous network of mortars is not reversible [22,23]. Compatibility requires that materials used for the treatment do not have negative consequences (e.g. harmful chemical reactions or formation of by-products), whereas retreatability implies that the present conservation treatment will not preclude or impede future treatments [23].

When the wall must be completely replaced due to its poor state of conservation, mechanical compatibility is an additional requirement. The new components should guarantee the same stiffness and ductility of the original construction system [22].

Safety level is another basic requirement (iii) not necessarily equal to what is mandatory for new constructions [24,25]. However, considering that the analysed buildings belong to a highly seismic area, design provisions for ensuring an acceptable level of damage mitigation are a priority.

Besides these requirements, the selection of solutions for the rehabilitation process depends on budgetary constraints and occupancy of the building plot by tenants or owners. A multi-stage project with a sequence of discrete rehabilitation actions can be a successful strategy; this type of intervention falls into the “incremental rehabilitation” category, whose advantages are shown in several reports by the U.S. Federal Emergency Management Agency (FEMA) [26,27].

2.2. Overview of intervention techniques on timber frame walls (TF)

Interventions on historical timber-framed constructions in seismic areas are scarcely regulated at a European level, even though national provisions have been settled in various countries. References on seismic design codes can be found in Italy (e.g. OPCM 3274) [28] and in Germany, where the maintenance of timber-framed buildings is regulated by specific norms and generally carried out by a multi-disciplinary team

Table 1
Strategy solutions reprocessed from [9].

Intervention strategy	Solutions for *Pombalino* buildings	Advantages	Limitations
1) Local modifications of the original configuration or 2) Removal or minimisation of existing irregularities and discontinuities	a) Demolition of extra (new) storeys b) Removal of incompatible elements, e.g. elevator shafts, concrete slabs, overhanging or inappropriate structures (rear facade) c) Removal of (new) openings and alterations in the interior layout	Maintenance of original layout; safeguarding of building's architectural value	Inconvenience to users; reduction of floor area; requires high level of workmanship; decrease in financial value
3) Global structural stiffening	a) Stiffening timber frame walls and floors b) New walls or structures		Inconvenience to users; high level of workmanship; reduction of floor area
4) Global structural strengthening	a) Strengthening with composite materials, without modifying the geometry of the walls or increasing their weight b) Partial grouting with reinforced concrete c) Local strengthening (e.g. connections of the timber elements and of the masonry walls)		High level of workmanship
	d) Closure of openings by precast cement elements	Pratical feasibility	Alteration of original configuration; increase in mass
5) Mass reduction	a) Demolition of additional storeys or removal of non-traditional partitions b) Removal of heavy furnshings		Inconvenience to users; reduction of floor area; decrease of the financial value
6) Seismic isolation	a) Inserting compliant bearings between the superstructure and the foundation	Reducion of seismic impact on structures	Excessive cost; requires high level of workmanship; low effectiveness for light and flexible components
7) Supplemental energy dissipation	a) Special devices for isolation for ground shaking b) Seisimic dissipator devices for walls	Maintenance of original layout, safeguarding of building's architectural value	High level of workmanship and cutting-edge methods

[29].

In the absence of a consistent European legislative framework, the authors referred to seven types of seismic upgrades as defined by FEMA [26].

The intervention sub-categories specified in Table 1 were evaluated by Coías [9] in reference to the *Pombalino* buildings, taking into account budgetary and feasibility constraints. Global structural strengthening (intervention strategy n.4) is recommended when the components show inadequate ductility and strength to resist large lateral deformation. As alternatives to strengthening and stiffening, mass reduction, seismic isolation, and supplemental energy dissipation (1a, 5a, 5b) are not considered feasible for this type of construction system.

Considering that extra floors in *Pombalino* buildings are fully integrated in the external configuration of the original construction for a number of reasons (e.g. alignment of the openings, roof/dormer geometry, architectural features), their demolition (1a) would incur a loss of the architectural value of the building, as well as a reduction of floor area and inconvenience to the users. This is also incompatible with the decision-makers' interests, due to a considerable decrease in the financial value of the investment.

This research regards interventions for structural stiffening and strengthening in timberframe walls (TF)(3a, 4a, 4b, 4c). Although conceived as a load-bearing structure that is included in a composite system interlocked with other components, TF was analysed independently from the timber joists and the external walls in order to focus attention on specific interventions for this component.

This work regards TF determined as retrofittable through visual grading and non-destructive testing (NDT). As a precondition for being repaired or strengthened, the timber framework will guarantee some residual capacity if the level of conservation, the effective cross-section, and deformations are acceptable [21]. It should also be pointed out that all interventions involve the removal of the surface finish, which should be preceded by a detailed documentation of the pre-intervention status quo [19].

A set of specific interventions was identified for each of the four sub-components: timber framework, infill, joints, and surface finish (Fig. 3, Table 2).

Individual options identified for those sub-components were re-grouped into 131 combinations, which were in turn divided into eleven groups according to the type of the intervention on the wall structure (F + I)(Table 3).

These 131 combinations were selected with the aim of grouping similar solutions across the sub-components in order to arrive at interventions that would be homogeneous for the whole wall. Such a homogeneous intervention would entail reasonable economic and practical feasibility, i.e. minimum number of types of material and skills required in the work site.

The definition of the main aim of the rehabilitation works is a crucial step; in fact, conservative repair implies preserving the original structural layout through the use of compatible products and techniques, i.e. with similar physical-mechanical features, and avoiding harmful chemical reactions or by-products. Conversely, slightly more intrusive interventions address the structural features with the main aim of meeting higher target reliability levels of the structure.

These alternatives include traditional methods (e.g. local replacement of decayed components by similar ones) or innovative materials (e.g. synthetic resins, fibre-reinforced polymers FRP) and new methods (e.g. externally bonded or near-surface-mounted – NSM – reinforcements) [30]. When prosthesis is required to strengthen the timber framework, the selected materials vary from improved traditional components (e.g. treated wooden members, plywood) to timber coupled with modern products (e.g. FRP, epoxy resin, NSM).

Similarly, improved traditional components or non-traditional materials can be used to replace the infill or the surface finish. Clay bricks and roof tiles belong to the first category, whereas mortars with hydraulic cement-based binder, render reinforced by fiberglass mesh, gypsum boards, and wood derivatives are examples of the latter. Finally, strengthening techniques for carpentry joints range from stainless-steel rods to externally bonded structural systems, such as Fibre Reinforced Polymer (FRP) systems [31].

Advantages and disadvantages as well as details and predictable failure modes of each intervention were extrapolated from an extensive literature review of current practice and experimental results [8,9,31–39].

In order to streamline the large number of possible combinations, the following separate interventions are equated in Table 3:

- *F3a* = *F3b*: due to comparable mechanical behaviour;

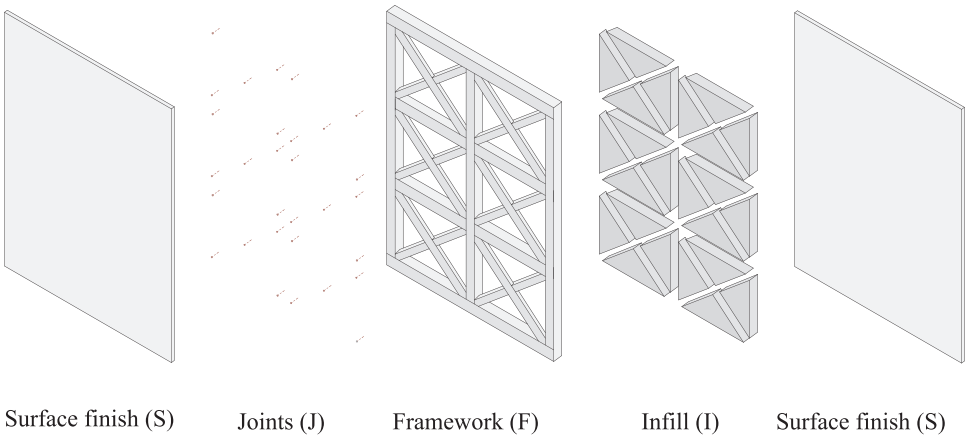

Fig. 3. Sub-components of timberframe wall (TF).

- *I1 = I2a*: different mechanical performances of these types of infill (brick or rubble masonry versus clay bricks or roof tiles) are not significant, since both include hydraulic lime mortar, which produces a similar response for the shear transfer mechanism and dissipative capacity.
- *J1a = J1b*: though there were different performance parameters of wooden versus metallic carpentry joints, such as moisture condensation in the timber-steel elements interface and low visual compatibility [38], these solutions can be equated for similar energy dissipation mechanisms and good ductility. Both dowel-type connections allow a mutual rotation of the elements.

3. Ranking of the rehabilitation techniques for timber frame walls (TF)

3.1. Macbeth analysis

A comprehensive comparison of Multi-Criteria Decision Analysis (MCDA) methods was addressed by Mustajoki et al. [2]. Due to the large number and great diversity of MCDA methods, it is difficult to justify the choice of a specific method for addressing a demanding decision problem. Arrow alleges that none of the existing MCDA methods can be considered faultless for all types of decision-making problems [1,39,40].

In keeping with all MCDA methods, Macbeth overcomes the limitation of mono-criteria models by including multiple and heterogeneous attributes. The efficacy of Macbeth has been demonstrated in different contexts, e.g. environmental planning, urban strategies, and eco-system management [4,5]. This problem-solving model is commonly used in literature by itself or coupled with other models like *Data Envelopment Analysis* (DEA) and *Utilitèt Additives* (UTA) [41,42].

Macbeth was chosen by the authors for its ability to incorporate a large number of preferences (or amount of subjective information) built through pairwise comparison judgments [4]. It can thus be tailored in order to match the specific requirements of the analysts, through a co-participative decision-making process. It also resolves contradictions between interests of single actors or with inconsistent scores by providing a complete ranking based on an additive aggregation approach [4].

In this research, a panel of experts (i.e. chemists, architects, and timber engineers) judged the performance of alternatives for each sub-component of the wall; this set of criteria-wise performances was numerically ranked in terms of attractiveness.

Macbeth is a user-friendly tool, since it can deal with inconsistent judgments in the pairwise comparison matrix and suggest solutions. This software is also intuitive, due to the graphical user interfaces (e.g. *thermometer*), and interactive, due to the possibility of analysing the sensitivity of every output based on variations of judgements, performances, and scores or weights [4,5].

However, this interactive model is time-consuming as it requires more questions than other elicitation methods (e.g. the swing weighting), especially when dealing with a high number of alternatives, criteria, and performance levels.

Additionally, other MCDA models use more accessible software packages than M-Macbeth; some are compatible with Microsoft Office (e.g. *Promax*, *Pure2*) and have MS Excel-like interfaces to input the data, or they can provide written reports (i.e. *1000Minds*, *Decision Tools*, *Hiview 3*, *Logical Decisions*, *MakeItRational*, *PlanEval*, *TESLA*, *V.I.S.A. Decisions*) [2].

3.2. Evaluation criteria

Five evaluation criteria and their respective performance descriptors were extrapolated from the commonly agreed guidelines for the conservation of architectural heritage (Section 2.1) (Table 4). This set of criteria satisfies Roy's axioms: exhaustibility, cohesion, and non-redundancy [43].

- *Material compatibility* (MC) regards the physical, chemical, and mechanical matching of the new (or reused) components to the original ones. MC is related to the impact of intervention on historical buildings in terms of durability and effectiveness.
- *Material permanence* (MP) regards the intrusiveness of the intervention and thus the possible material variation of the authenticity of the original components. It is inversely proportional to the volume of the material to be removed.
- *Structural reliability* (SR) is evaluated by comparing the mechanical behaviour of the component (e.g. resistance, ductility, and energy dissipation) before and after the intervention.
- *Structural authenticity* (SA) is based on the level of modification of the original structural system (either geometrical or structural configuration of timber frame walls), which influences the structural performance in terms of stiffness, mass distribution, and loading level.
- *Visual-tactile appearance* (VTA) regards the aesthetic compatibility of the intervention on wall surface appearance. The aesthetic compatibility typically belongs to the material compatibility (MC); however, it was considered in this dedicated criterion in order to avoid redundant evaluations.

3.3. Problem structuring

This process included two main steps: the evaluation of 131 rehabilitation techniques based on each criterion (Section 3.2) in a 0–100-scale by the experts on historic timber frame buildings (Fig. 4, 1st – 4th step) and the definition of three scenario models (Fig. 4, 5th

Table 2
Interventions for each sub-component of the timber frame wall (TF).

Timber frame wall components	Main aim	Sub-Intervention	Description	References
FRAMEWORK	Removal of causes of degradation (e.g. corroded iron elements and decayed timber elements) and preservation or reconstitution of the structural continuity of the wall	**F1**	**Removal of decayed timber elements and replacement with autoclaved timber components**	Appleton [8]; Appleton and Domingos [32]; Campanella and Mateus [33]
		F2	**Substitution of decayed timber elements with wooden prosthesis using:**	
		F2a	Structural timber glue	Tsakanika-Theoharis [34]
		F2b	CFRP or GFRP bars+ Epoxy resin	Pizzo et al. [30]; Cruz et al. [31]; Gonçalves et al. [35]
		F2c	Steel rods + Epoxy resin	Poletti and Vasconcelos [11]
		F2d	Stainless steel screws	Tsakanika-Theoharis [34]
		F3	**Introduction of stainless steel structure by using:**	
		F3a	Stainless steel cross-bracing	Appleton [8]
		F3b	Stainless steel beams/columns with bolted and welded plates	Mascarenhas [7]
		-	Diagonal damper	Gonçalves et al. [35]
INFILL		**I1**	**Partial removal of infill and repair of the brick or rubble masonry with natural hydraulic lime mortar**	Appleton and Domingos [32]; Bianco [36]
		I2	**Total or partial replacement of the existing infill by using:**	
		I2a	Clay bricks (or roof tiles) grouted with hydraulic lime mortar	Appleton [8]; Gonçalves et al. [35]; Bianco [36]
		I2b	Hollow bricks grouted with cement mortar	Appleton and Domingos [32]
		I2c	Mineral wool	Appleton and Domingos [31]
		I3	**No infill**	Poletti and Vasconcelos [10]
		F4 + I4	**Restoring the wall to its original condition and placement of reinforced rendering**	Appleton [8]; Appleton and Domingos [32]; Gonçalves et al. [35]
JOINTS	Local recovery and strengthening of the original function	**J1**	**Recovery of carpentry joints by using:**	
		J1a	Wooden pegs and pins	Tsakanika-Theoharis [34]
		J1b	Stainless steel nails	Bianco [36]; Poletti and Vasconcelos [10]
		J2	**Strengthening carpentry joints:**	
		J2a	Stainless steel bolts	Poletti and Vasconcelos [10]
		J2b	Stainless steel plates with bolts	Gonçalves et al. [36]; Poletti and Vasconcelos [10]
		J2c	Self-tapping stainless steel screws	Poletti and Vasconcelos [10]
		J2d	NSM (steel bars or FRP bars)	Cruz et al. [31]; Poletti et al. [37]
		J2e	EBR (GFRP or CFRP)	Cóias [9]; Poletti and Vasconcelos [10]
SURFACE FINISH	Protection of the surface wall	**S1**	**Mono or multi-layer plaster by using:**	
		S1a	NHL-based and/or lime-based render reinforced by fiberglass mesh	Appleton [8]
		S1b	HL or cement-based mortar	
		S2	**Cement-based mortar with metal mesh (or fibreglass) with acrylic (or polymer) render/additives**	Appleton [8]; Appleton and Domingos [32]; Gonçalves et al. [35]
		S3	**Lining panels:**	
		S3a	Plasterboard	Appleton and Domingos [32]
		S3b	Strips of wood with lime-based mortar	Tsakanika-Theoharis [34]
		S4	**Surface film:**	
		S4a	Transparent scumble glaze	Campanella and Mateus [33]
		S4b	Coating finish with pigment	

Table 3
Combinations of interventions on timber frame wall (TF).

Intervention	Wall Structure	Joints	Surface Finish	Intervention	Wall Structure	Joints	Surface Finish	Intervention	Wall Structure	Joints	Surface Finish	Intervention	Wall Structure	Joints	Surface Finish
Group 1				**Group 3**				**Group 5**				**Group 8**			
TF01	F1 + I1 (*or*	J1a	S1a	TF43	F1 + I2c	J1a (or	S2	TF82	F2a + I1 (*or* F2a	J1a (or	S1a	TF120	F2d + I2b	-	S1b
TF02	F1 + I2a)	(orJ1b)	S3a	TF44		J1b)	S3a	TF83	+ I2a)	J1b)	S2	TF121			S2
TF03			S3b	TF45			S3b	TF84			S3a	TF122			S3a
TF04		J2a	S1a	TF46		J2a	S2	TF85			S3b	TF123			S3b
TF05			S3a	TF47			S3a	**Group 6**				**Group 9**			
TF06			S3b	TF48			S3b	TF86	F2b + I1 (*or* F2b	J1a (or	S1a	TF124	F2d + I2c	-	S1b
TF07		J2b	S1a	TF49		J2b	S2	TF87	+ I2a)	J1b)	S2	TF125			S2
TF08			S3a	TF50			S3a	TF88			S3a	TF126			S3a
TF09			S3b	TF51			S3b	TF89			S3b	TF127			S3b
TF10		J2c	S1a	TF52		J2c	S2	TF90		J2a	S1a	**Group 10**			
TF11			S3a	TF53			S3a	TF91			S3a	TF128	F3a (*or* F3b)	-	S2
TF12			S3b	TF54			S3b	TF92			S4a	TF129			S3a
TF13		J2d	S1a	TF55		J2e	S2	TF93		J2b	S1a	**Group 11**			
TF14			S3a	TF56			S3a	TF94			S3a	TF130	F4 + I4	-	S1b
TF15			S3b	TF57			S3b	TF95			S4a	TF131			S3a
TF16		J2e	S1a	**Group 4**				TF96		J2c	S1a				
TF17			S3a	TF58	F1 + I3	J1a (or	S3a	TF97			S3a				
TF18			S3b	TF59		J1b)	S3b	TF98			S4a				
Group 2				TF60			S4a	TF99		J2d	S1a				
TF19	F1 + I2b	J1a (*or*	S1b	TF61			S4b	TF100			S3a				
TF20		J1b)	S2	TF62		J2a	S3a	TF101			S4a				
TF21			S3a	TF63			S3b	**Group 7**							
TF22			S3b	TF64			S4a	TF102	F2c + I1 (*or* F2c	J1a	S1a				
TF23		J2a	S1b	TF65			S4b	TF103	+ I2a)	(orJ1b)	S3a				
TF24			S2	TF66		J2b	S3a	TF104			S3b				
TF25			S3a	TF67			S3b	TF105		J2a	S1a				
TF26			S3b	TF68			S4a	TF106			S3a				
TF27		J2b	S1b	TF69			S4b	TF107			S3b				
TF28			S2	TF70		J2c	S3a	TF108		J2b	S1a				
TF29			S3a	TF71			S3b	TF109			S3a				
TF30			S3b	TF72			S4a	TF110			S3b				
TF31		J2c	S1b	TF73			S4b	TF111		J2c	S1a				
TF32			S2	TF74		J2d	S3a	TF112			S3a				
TF33			S3a	TF75			S3b	TF113			S3b				
TF34			S3b	TF76			S4a	TF114		J2d	S1a				
TF35		J2d	S1b	TF77			S4b	TF115			S3a				
TF36			S2	TF78		J2e	S3a	TF116			S3b				
TF37			S3a	TF79			S3b	TF117		J2e	S1a				
TF38			S3b	TF80			S4a	TF118			S3a				
TF39		J2e	S1b	TF81			S4b	TF119			S3b				
TF40			S2												
TF41			S3a												
TF42			S3b												

Table 4
Evaluation criteria and performance descriptors.

Criterion	Sub-criterion		Performance descriptors
Material Compatibility (MC)	**physical compatibility**		porosity and pore size distribution, variation of the moisture transport properties, such as absorption and drying rate, thermal, and hygric expansion
	chemical compatibility		chemical composition and reactions, solubility
	mechanical compatibility		hardness, cohesion, and deformation
Material Permanence (MP)	**degree of intrusiviness**		permanence of original components after the intervention
Structural Reliability (SR)	**resistance**		horizontal and vertical load capacity
	ductility and energy dissipation		lateral deformation capacity; ability to deform and mechanically degrade without collapse
Structural Authenticity (SA)	**consistency with the:**	**original structural layout**	mass distribution, stiffness, and load concentration
		structural wall typology and joint type	dissipation capacity of walls and joints
Visual-Tactile Appearance (VTA)	**visual appearance**		visual permanence of the original features before and after the intervention (thickness, colour, gloss)
	tactile appearance		tactile permanence of the features before and after the intervention (roughness)

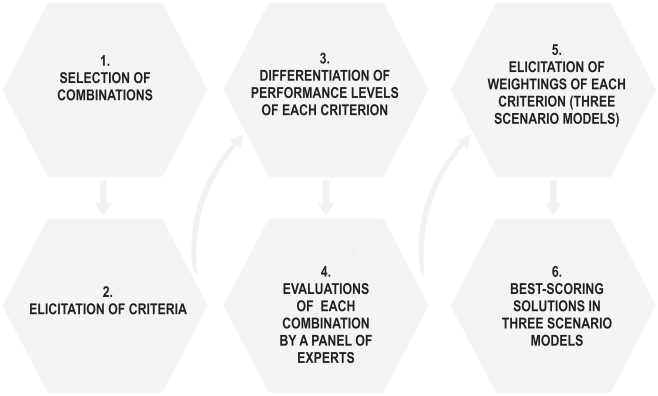

Fig. 4. Workflow analysis.

step).

The panel of experts, whose technical knowledge is based on scientific literature, worksite practice, and laboratory tests, was composed of two representatives for each field: chemistry, timber engineering, and architecture. The elicitation of the best-scoring solutions was influenced by their respective disciplinary sphere. Chemists evaluated the alternative options under MC criterion, architects (experts of architectural heritage preservation) under MP and VTA criteria, and timber engineers under SR and SA criteria.

Once the qualitative performance descriptors of each criterion were established (Table 4), the experts determined the respective performance evaluation levels (high, moderate, low, or very low)(Table 5), whose interval values were defined through Macbeth pairwise questioning procedure.

In order to obtain numerical values, it was necessary to more clearly define the distances involved between the various evaluation levels. These would vary for judgments about different sub-components. The experts defined the difference of attractiveness between two levels of performance by selecting the most suitable adjective among seven semantic categories included in the Macbeth method (no, very week, week, moderate, strong, very strong, or extreme).

It was therefore possible to determine under the Material Compatibility criterion, for example, that the difference in attractiveness between High and Moderate evaluations was “very strong” in reference to Framework Infill and Joints, while when considering surface finish the difference between High and Moderate was seen as “weak”. These qualitative expert judgments were translated into cardinal values by M-Macbeth (Figs. 4 and 5).

The difference of attractiveness between the sub-components of TF was determined through the same pairwise procedure for all criteria except for the visual-tactile appearance (VTA). In fact, VTA is related only to the surface finish, and thus the evaluations were performed directly for the whole wall (Fig. 7).

Additionally, the threshold between what constitutes repair versus strengthening measures is proposed below by using the weighted assessment of the combinations in the SR criterion. The threshold value ($t_{r\text{-}s}$) was determined by calculating the weighted average of the evaluation level defined as “low” (EL_p) of the SR criterion, as shown in Eq. (1):

$$t_{r-s} = \sum_i (ELp_i \bullet WF_i) \tag{1}$$

where WF_i is the weighting of each sub-type of intervention (rehabilitation technique) used to determine each partial value score of the evaluation under SR criterion.

The result for $t_{r\text{-}s}$ can be rounded up to 30 (Eq. (2)):

$$t_{r-s} = 41 \times 0.35 + 25 \times 0.55 + 15 \times 0.10 = 29.6 \tag{2}$$

where 41, 25, and 15 are the value scores of the evaluation level ‘low’ attributed respectively to F + I, J, and S (Fig. 4), whereas 0.35, 0.55, and 0.10 are the weightings respectively attributed to F + I, J, and S (Fig. 6, Table 6, numbers in bold).

The next step of this analysis consisted of the assignment of a relative weight to each criterion. This step involved setting up separate Macbeth models corresponding to three design-related models (Fig. 8, Value tree). These are listed according in ascending order of intrusiveness of the intervention, depending in turn on the degree of authenticity and on the level of structural safety of the building (Table 7).

Finally, each scenario, to which the value scores of the options are associated, can be selected by the decision-maker (building owner or users) on the basis of the state of conservation of the building components (Table 7).

4. Results and discussion

4.1. A set of incomparability and consistency of pairwise evaluations

A set of incomparability, arising from possible diverging judgments of the experts on the different criteria [1] can be identified, for example in relation to a pairwise comparison of the global scores of material compatibility (MC) versus structural reliability (SR)(Fig. 9, Table 8). In fact, the individual scores of these solutions reach the highest value for MC and low values for SR. This reflects the different weightings attributed respectively by timber engineers and by chemists (Section 3.3) to the repair measures on the joints (J1a or J1b) in the calculation of the global assessment for these criteria. When evaluating MC, the intervention on the joints is weighted by a very low value (0.08), whereas it is weighted by a high value (0.55) when referring to the structural reliability (Table 6).

Another incomparability arises in the case of lack of replacement of

Table 5
Performance levels for each criterion based on experts' judgments.

Criterion	Performance levels	
Material Compatibility (MC)	**High (H)**	Properties are similar physically (e.g. very similar porosity and pore size distribution, very low variation of the moisture transport as absorption and drying rate, no thermal and hygric expansion), chemically (e.g. identical chemical composition, no harmful chemical reaction, similar solubility) mechanically (e.g. hardness, cohesion and deformability similar to the original material). Additionally, the treatment will have a long-term durability.
	Moderate (M)	Slightly or moderately different physical-mechanical features (e.g. moderate variation of the porosity and pore size distribution, moderate variation of the hardness/cohesion, moderate variation of drying and hygroscopic behaviour, different chemical features, no harmful chemical reaction or byproducts).
	Very Low (VL)	Different from the original properties (e.g. chemical composition and solubility, formation of byproducts, remarkable difference in hardness and deformability, very different drying behaviour).
Material Permanence (MP)	**High (H)**	Negligible replacement of original components.
	Moderate (M)	Limited replacement of original components.
	Low (L)	Significant replacement of original components.
	Very Low (VL)	Complete replacement of original components.
Structural Reliability (SR)	**High (H)**	Significant improvement of mechanical behaviour (resistance, ductility, and energy dissipation).
	Moderate (M)	Moderate improvement of mechanical behaviour (resistance, ductility, and energy dissipation).
	Low (L)	Low improvement of mechanical behaviour (resistance, ductility, and energy dissipation).
	Very Low (VL)	Non significant improvement or even worsening of the mechanical behaviour (resistance, ductility, and energy dissipation).
Structural Authenticity (SA)	**High (H)**	The original geometry and structural configuration are mantained.
	Moderate (M)	About the same geometry and structural configuration as the original ones.
	Low (L)	Different from the original geometry and structural configuration.
	Very Low (VL)	Very different from the original geometry and structural configuration.
Visual-Tactile Appearance (VTA)	**High (H)**	Visual, tactile, and spatial features are similar to the original.
	Moderate (M)	Spatial features are similar to the original, wheras the tactile consistency is different.
	Low (L)	Increase of thickness, differences in tactile and material consistency.
	Very Low (VL)	Relevant differences in thickness and in tactile, material, and colour consistency.

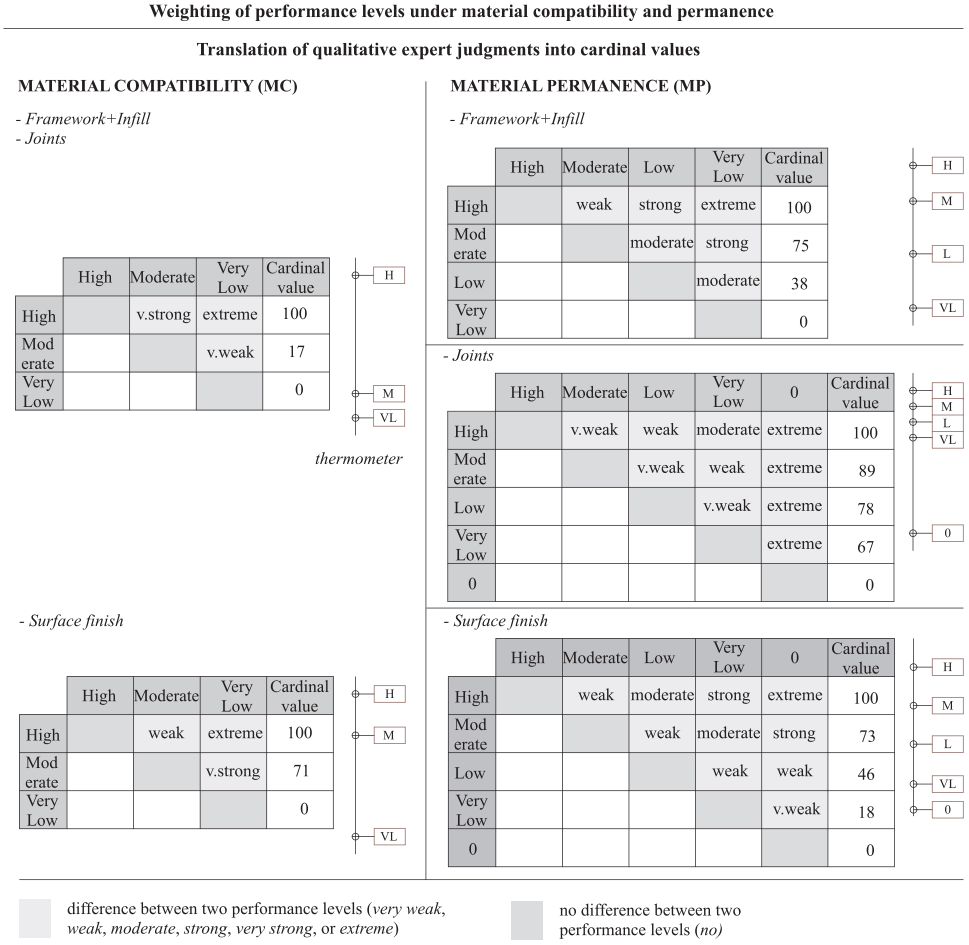

Fig. 5. Macbeth judgment matrices related to the difference of attractiveness between the performance levels of MC and MP.

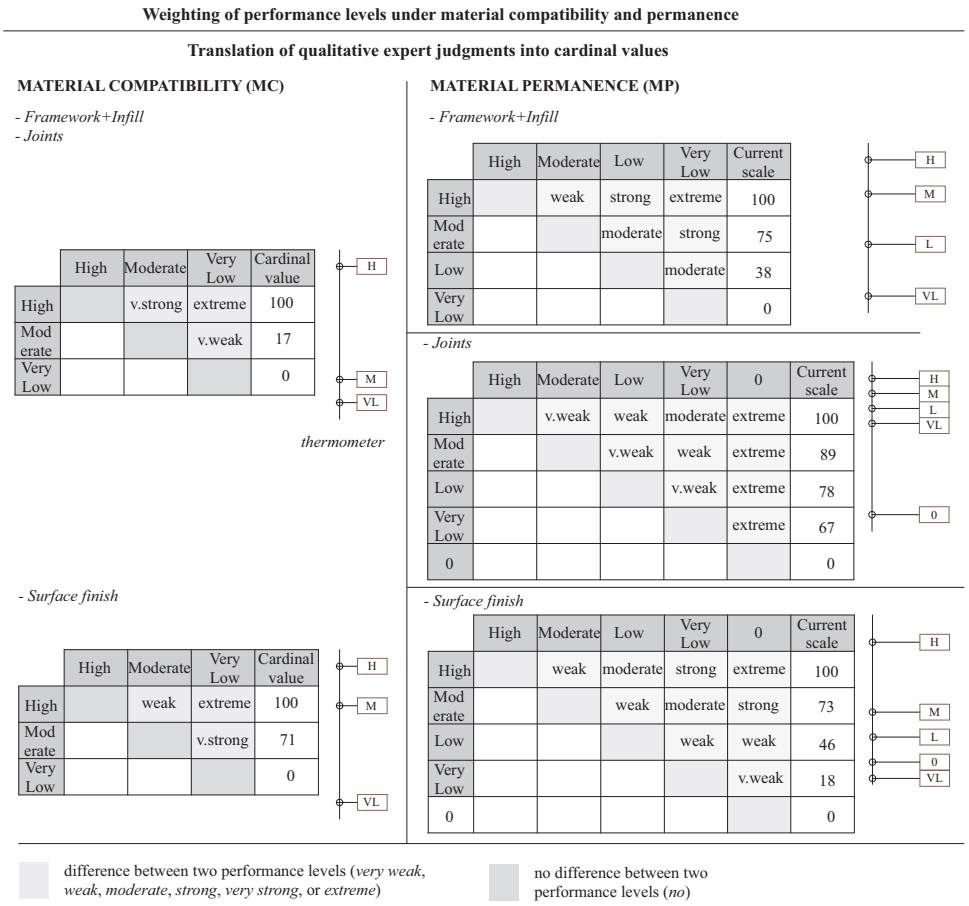

Fig. 6. Macbeth judgment matrices related to the difference of attractiveness between the performance levels of SR and SA.

the infill (F1 + I3, Table 3): in the set of solutions between TF58 and TF81, MC ranges from 86 to 79, whereas VTA equals 11, as shown in Table 8 (left).

On the other hand, the evaluations of MC and of SA show consistent outputs (Table 8, left).

The best-scoring solutions for MC also score the best for SA (e.g. TF01-TF03, Group 1). However, this consistency is not found when the surface finish is made of cement mortar (S1b), or of cement-based mortar with metal mesh and acrylic render (S2). In these cases, the solutions achieve only moderate scores for SA, due to the low weighting (0.10) applied to the surface finish under SA. Conversely, the low scores for MC result from the high weighting attributed to surface finish (0.50) (Table 6).

4.2. Predominance of five best solutions in three selected scenarios

In order to provide a preliminary screening of the results, all combinations characterized by a low global weighted score in all three scenarios (lower than 50) were discarded; 74 options were thus excluded from the following analysis.

Based on the different target reliability levels – repair or strengthening measures – each distinct solution was evaluated as a function of its specific applicability to each scenario:

- The first scenario consists of repair measures whose structural reliability values are lower than 30 (28 options);
- The second scenario consists of a combination repair and strengthening measures (39 options);
- The third scenario consists of strengthening measures whose structural reliability values are higher than 30 (29 options).

The high weighting of material compatibility (MC) in all scenarios (Table 7) results in the best-scoring solutions all belonging to Group 1 (Figs. 9 and 10).

The best set of solutions to adopt within these three selected scenarios is highlighted in Table 9.

These five best-scoring solutions consist of similar interventions on timber framework, infill, and surface, whereas they differ on four types of intervention for the joints. Therefore, under the same interventions on the wooden components and surface finish, additional criteria can be taken into account for the comparison of these best solutions, i.e. the average costs and time required to repair or strengthen the joints.

A proper carpentry joint recovery can be carried out only by an experienced timber framer by drilling peg holes and using wooden pegs and pins (draw boring). Additionally, repair procedures are quite time demanding. Recourse to bolts or self-tapping screws can save time and keep costs low (not more than 12€ per wall), whereas the use of steel plates, although not time-consuming (the application can be accomplished in one day), substantially increases the costs (approximately 130€ per wall). Lastly, retrofitting performed with NSM steel flat bars is somewhat more affordable than steel plates (around 100€ per wall), yet it takes 8 days to retrofit one wall (1 day for opening the slots and 7 days to apply the glue and let it dry). Moreover, precise workmanship is required to open the slots.

4.3. Research limitations and forthcoming perspectives

The main limitations of this study regard different aspects: problem structuring, scope of application, gaps in scientific understanding (or dissemination of experimental data) related to the original components, and potential disconnect between the evaluation in theory and the real result of the interventions (arising from questions of quality of workmanship).

Firstly, this research process is time-consuming due to the large

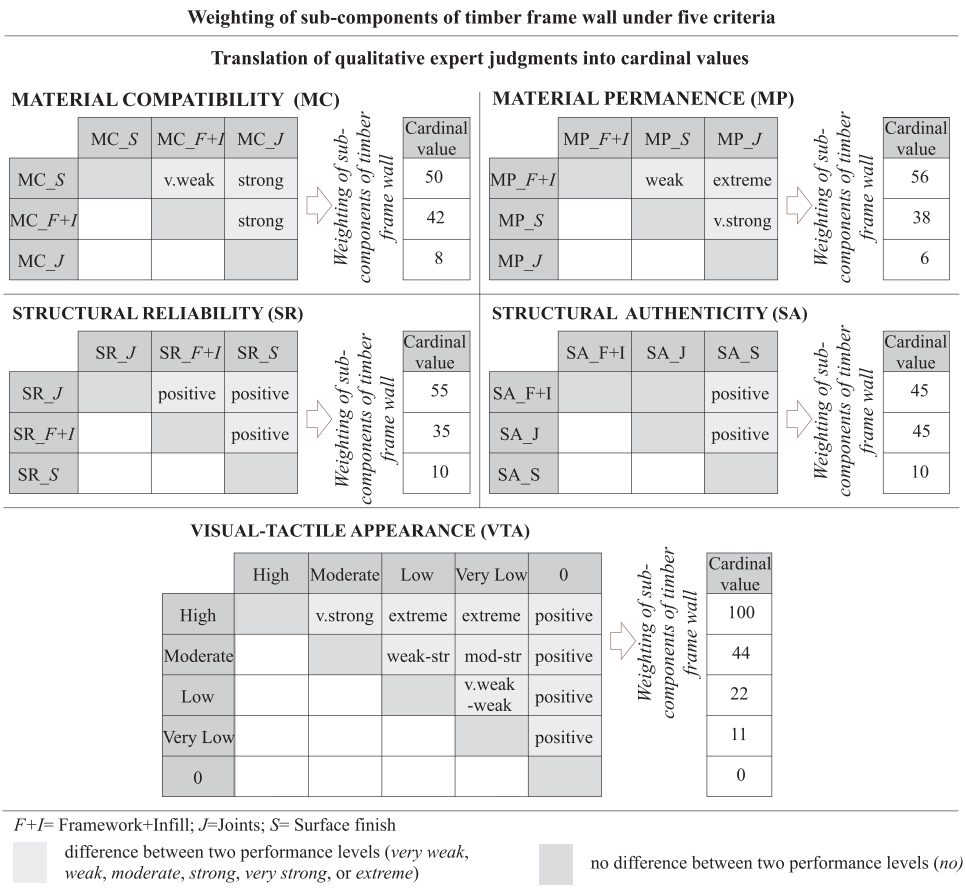

Fig. 7. Macbeth judgment matrices related to the difference of attractiveness between each sub-component of TF in each criterion.

Table 6
Summary chart of cardinal values calculated from Macbeth matrices.

Criterion	Sub-component of TFW	Weights	Evaluation level (EL)				
			H	M	L	VL	0
Material compatibility (MC)	F+I	0.42	100	17	-	0	-
	J	0.08	100	17	-	0	-
	S	0.50	71	17	-	0	-
Material permanence (MP)	F+I	0.56	100	75	38	0	-
	J	0.06	100	89	78	67	0
	S	0.38	100	73	46	18	0
Structural reliability (SR)	F+I	0.35	100	71	41	20	0
	J	0.55	100	58	25	8	0
	S	0.10	100	47	15	7	0
Structural authenticity (SA)	F+I	0.45	100	80	35	20	0
	J	0.45	100	70	25	10	0
	S	0.10	100	70	35	10	0
Visual-tactile appearance (VTA)	-	-	100	44	22	11	0

number of model inputs and the poor interoperability and interface of data. On the other hand, the fast processing of the outputs makes it feasible to re-run the analysis while varying specific inputs.

Secondly, the authors are evaluating the impact of a set of interventions on a single construction component whose behaviour actually depends on the global performance and interactions of other members. The experts' judgments are affected by uncertainty around the real configuration of this composite system.

Thirdly, despite a considerable scholarly interest in this type of wall and the current need to recover timber-framed buildings in several countries (including Portugal), several knowledge gaps can be still identified. Experts' uncertainty arises from a lack of information related to the impact of the combined rehabilitation measures of all sub-components of the timber frame wall. Recent laboratory campaigns in Portugal on un-reinforced and reinforced tested specimens of TF clarify the influence of the infill and the effectiveness of the interventions on the joints in the mechanical behaviour but do not provide sufficient data as regards the interaction of the structure wall (F + I) and the surface finish (S) under static and cyclic loadings [10,35]. As matter of fact, the placement of surface finish on the specimens was completely neglected in these frame tests, although an increase of the stiffness and of the mechanical strength of the whole system can be induced by a simple modification of the surface finish thickness. Conversely, the seismic performance of plastered timber frames of traditional Turkish buildings (*himis*) under reverse-cyclic loading was evaluated by Aktas and Turer [44].

Additionally, experts' evaluations are probabilistic. These concern ideal solutions and thus neglect several factors that may occur at the work site, one of which is related to the quality of workmanship. In fact, as noted by Aktas and Turer [44] for traditional timber-framed systems in Turkey and also valid for this case study, the quality of workmanship strongly influences the reliability of the intervention for the lateral load–displacement relationships and for the overall behaviour of the wall. These scholars observe a variation in quality for work done even by the same group of builders on a limited set of frames. In particular, the quality of the connection (e.g. number of nails at each connection and their driving angles), which influences the strength and stiffness, may vary from frame to frame within the same wall. Poor detailing, lack of proper reinforcement in the joint region, or lack of proper infill geometry can cause brittle failure mechanisms at the local level [44]. This makes it difficult to generalize the findings of these frame tests, and thus may affect the objectivity of the evaluation under the SR criterion.

Regardless of these aspects, the novelty of this research is two-fold:

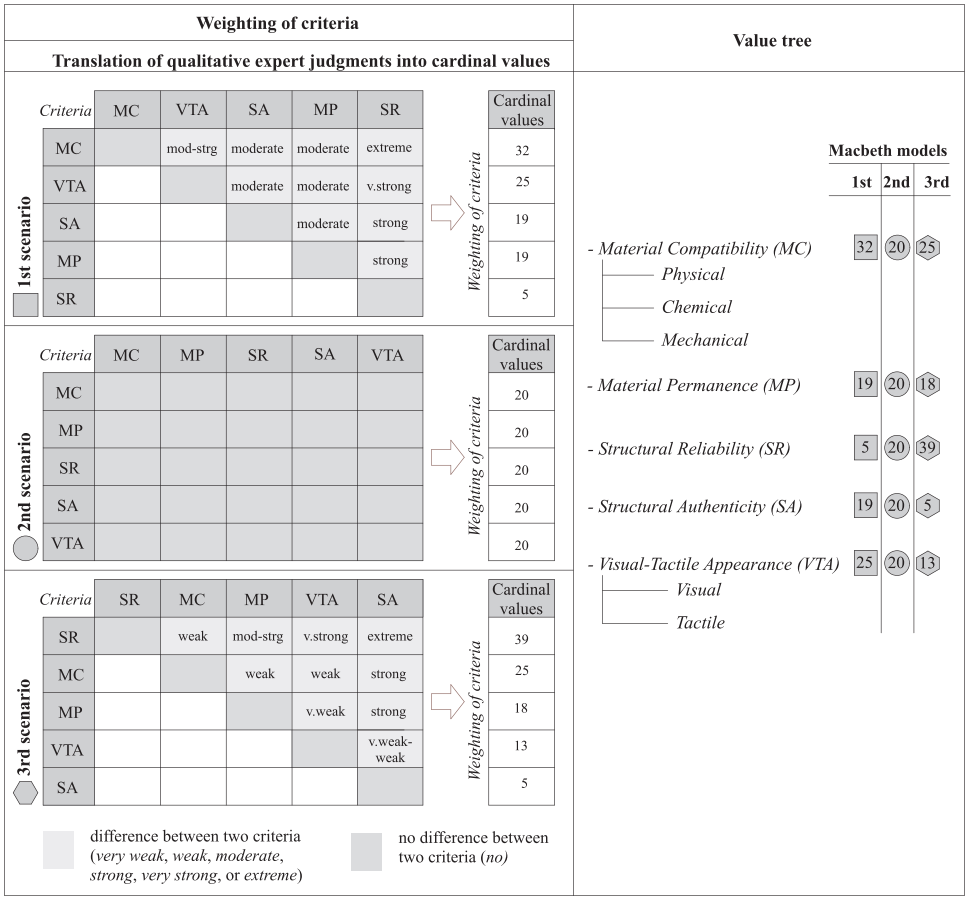

Fig. 8. Macbeth judgment matrices related to the difference of attractiveness between each criterion (three scenario models).

firstly, an overview of the current intervention techniques for traditional timber frame walls is provided from an extensive survey; secondly, the involvement of a technical panel of experts on rehabilitation techniques is examined under a variety of criteria.

Although built heritage conservation demands a multi-disciplinary approach and involves multifaceted cultural and economic value, the current practice is largely determined by the requirements or preferences of relatively few decision makers. As an alternative, a well-informed, interactive, and transparent procedure is called for. To this end, this research includes the involvement of multi-disciplinary experts in conservation sciences throughout all phases of problem structuring (Fig. 4).

Once the decision-making process has been concluded, the following questions can be addressed:

1. *What are the greatest advantages and drawbacks of using Macbeth or other multi-criteria analysis tool in the domain of the built heritage rehabilitation?*

The benefits of using of Macbeth analysis are the involvement of multi-disciplinary experts and the possibility of evaluating different options under tailor-made parameters for the domain of cultural heritage, i.e. non-numerable, non-homogeneous, and conflicting criteria. Experts frequently have difficulty assigning a direct numerical value to the weightings of criteria and their performance levels. As shown in this research, they feel more comfortable in making comparisons through semantic judgments by expressing the importance (or attractiveness) of preferences between every element of evaluation.

The goal is to reach a consensus within a group of experts, some of whose standpoints are conflicting, by fostering a debate during the attribution of semantic value to the difference between each pair of attributes.

2. *From the different standpoints of the group of experts, which alternatives are expected to score best?*

The expected best-scoring alternatives for each group of experts, with the respective value scores processed by Macbeth, are almost

Table 7
Scenarios and best-scoring solutions obtained by Macbeth analysis.

Pre-existing conditions of the building		Scenario model	Criteria Weightings (%)					1st quarter best-scoring solutions
Degree of integrity and authenticity	Level of structural safety		MC	SR	SA	MP	VTA	
High	Satisfactory	1st	32	5	19	19	25	TF01:88. 67 TF04 = TF10: 84.55 TF82 = TF86 = TF102: 74.99
Medium	Satisfactory	2nd	20	20	20	20	20	TF13: 78.40 TF07: 77.19 TF01: 76.16
Low/Very Low	Unsatisfactory	3rd	25	39	5	18	13	TF13: 78.24 TF07: 77.94

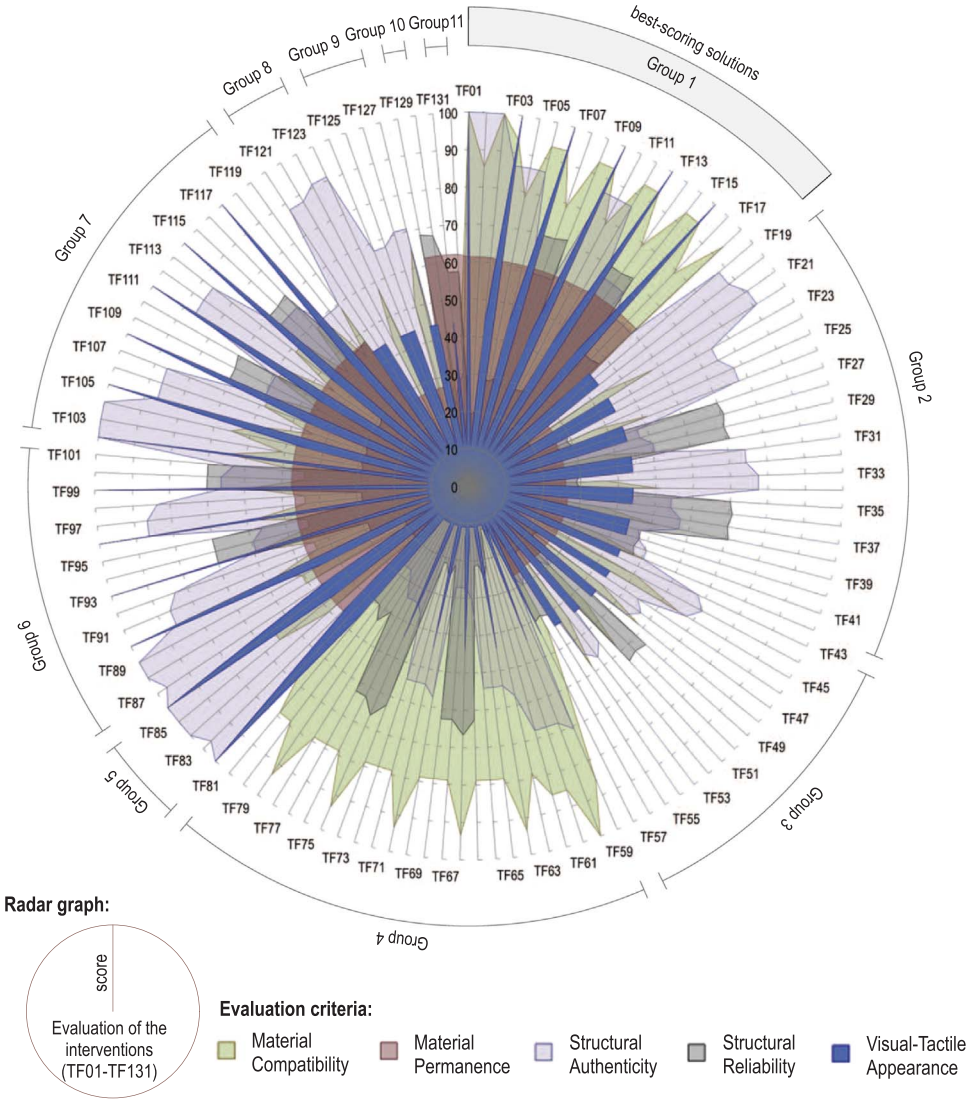

Fig. 9. Evaluations under five criteria: Incomparability and consistency.

entirely different depending on field of expertise.

A comparison of the 1st quarter of the best solutions (Table 7) and the expected best-scoring alternatives, which reflect the experts' preferences (value scores > 70/100, Fig. 11), shows that most of Macbeth's results were predictable, especially for the chemist and architect groups. We can note that the best-scoring solutions for MP criterion do not reach 70/100, because all the analysed solutions involve surface removal (Fig. 11).

3. *Can a compromise be found between multiple and conflicting aims and practical solutions in current rehabilitation works?*

The five best-scoring solutions identified in Table 9 integrate standpoints and preferences of a multi-disciplinary panel of experts within three design-related scenarios. Balancing a variety of criteria, these solutions can be recommended by the technicians to the building owner and finally employed by the contractors.

Table 8
Incomparability and consistency of pairwise evaluations (on left: MC vs SR, MC vs SA; on right: MC vs VTA).

Intervention	Evaluations			Intervention	Evaluations	
	SR	MC	SA		MC	VTA
TF01	19	100	100	**TF02, TF58, TF60**	86	11
TF02		86		**TF61**		
TF03	20	100		**TF05, TF08, TF11, TF14, TF17, TF19, TF62, TF64/TF66, TF68/TF70, TF72/TF74, TF76/TF78, TF80,**	79	11
TF04	29	93	87	**TF81**		
TF06	30					
TF10	29					
TF12	30					
TF59	16	100	70			
TF63	25	93				
	INCOMPARABILITY				*INCOMPARABILITY*	
		CONSISTENCY				

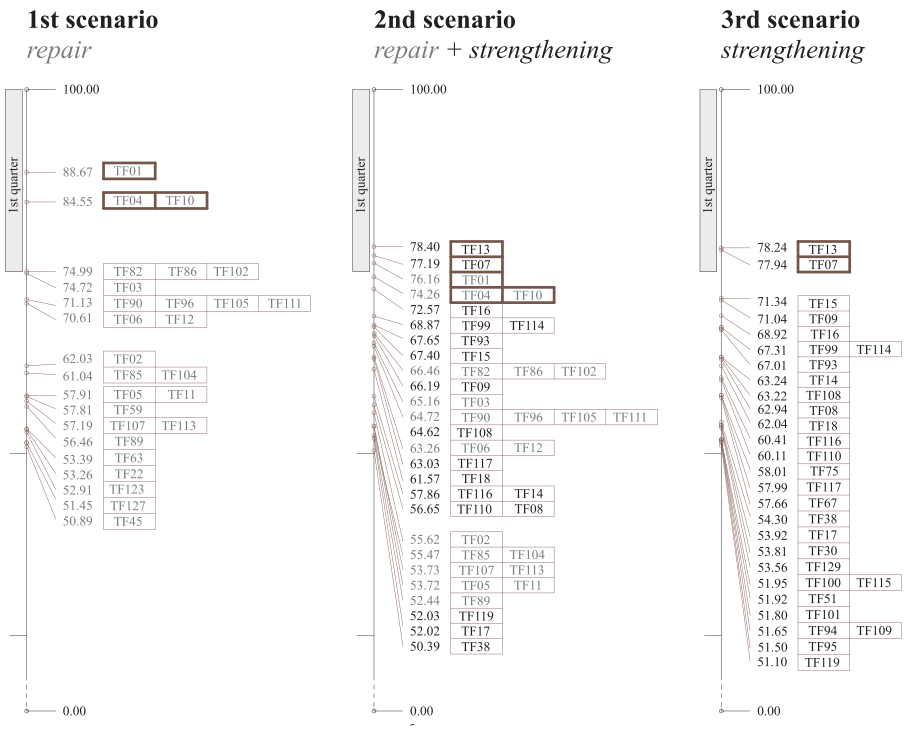

Fig. 10. Visual scoring: 1st, 2nd, 3rd scenario.

Table 9
Best-scoring solutions obtained by Macbeth analysis.

Intervention	Aim	Sub-type of intervention		
		Framework + INFILL (F + I)	**Joints (J)**	**Surface finish (S)**
TF01	*repair*	**F1:** Substitution of local decayed timber elements with autoclaved timber components	**J1a:** Recovery of carpentry joints using: wooden pegs and pins *or* **J1b:** stainless steel nails	**S1a:** Mono or multi-layer plaster by using NHL-based and/or lime-based render reinforced by fiberglass mesh
TF04	*repair*	*+ either*	**J2a:** Strengthening carpentry joints using stainless steel bolts	
TF07	*strengthening*	**I1:** Partial removal of infill and repair of the brick or rubble masonry	**J2b:** Strengthening carpentry joints using stainless steel plates with bolts	
TF10	*repair*	*or*	**J2c:** Self-tapping stainless steel screws	
TF13	*strengthening*	**I2a:** Replacement of infill using clay bricks (or roof tiles) and hydraulic lime mortar	**J2d:**Strengthening carpentry joints using NSM (steel bars or FRP bars)	

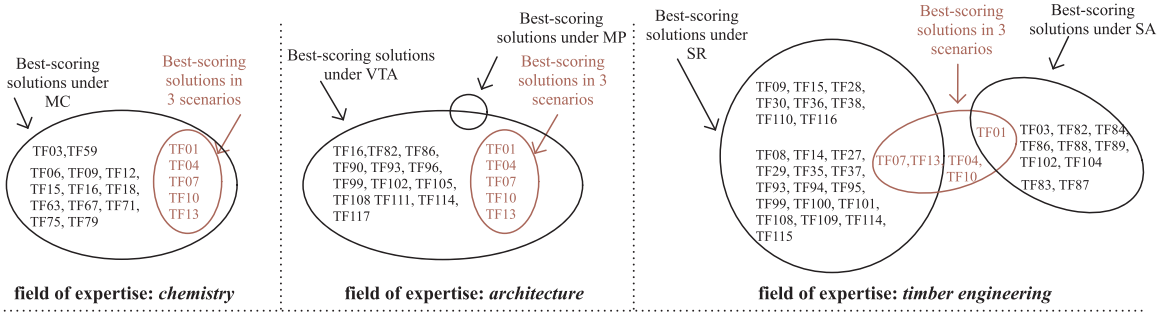

Fig. 11. Expected best-scoring solutions from different fields of expertise.

5. Conclusions

The rehabilitation of historic buildings is a complex task, affected by different instances arising from users' and property developers' interests, code-required actions, and the need to preserve the cultural significance of the construction. Conflicting aims pursued by multiple stakeholders can threaten the cultural value of the architectural heritage, especially in contexts of high real estate demand, as is currently the case in downtown Lisbon.

In this research, the question of the best rehabilitation techniques for the traditional timber frame wall was examined under a variety of criteria by dedicated software (M-Macbeth, *Measuring Attractiveness by a Categorical-Based Evaluation Technique*).

The main limitations of this research were identified during the problem structuring and throughout the assessments of the rehabilitation techniques influenced by a lack of adequate specific information

(or dissemination of experimental data) related to the original components and by the quality of workmanship, which may significantly affect this analysis.

Some limitations of this research related to the uncertainty of the experts could be approached by robustness analysis using Macbeth. Future laboratory testing might also shed light on the seismic impact varying the type of surface infill and these results might influence the expert' judgments.

Future applications of the Macbeth analysis can support the selection of the best practice for different types of vertical structure of traditional timber framed buildings, i.e. masonry reinforced with timber frames, rubble store masonry or partitions walls. Moreover, this methodology can be further applied to other scenario models that embrace different requirements of the owners or users, e.g. energy saving and cost effectiveness.

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