ISBN 978-989-9121-31-7
2nd International Conference on Challenges in Engineering, Medical, Economics and Education: Research & Solutions (CEMEERS-23b)
Istanbul (Turkiye) Nov. 23-24, 2023

Developing A Structure for Surveying Portuguese Dwellings: Integrating Inspection and Heritage Conservation Theory in Practice (Part II)

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***Abstract*:** *A model suitable for the evaluation of the state of conservation of older buildings, applicable to a Portuguese setting, was presented in a previous edition of this conference. This model emerged from a review of a substantial body of relevant Portuguese and international work from the past two decades, to ensure a transparent, integrated approach to decision-making when intervening in the historic built environment. The model divides structures into their individual components – walls, flooring, ceilings, roofs and terraces and drainage – whilst understanding their interconnected nature. This paper, the second part of the series, presents and explores the model in further detail, critically engaging with how it works when implemented in the real world, specifically with regard to the "walls" component. The paper examines the model's data collection, analysis and prognosis processes and, drawing from extensive practical data, discussing the model's effectiveness in identifying main pathologies by type of construction and in doing so evaluating its effectiveness when applied to a fuller range of residential buildings in Continental Portugal.*

Keywords: *Heritage conservation; building pathology; legal and regulatory compliance; planning policy and evidence base; sustainable development; masonry; walls.*

1. Introduction

The first part of this paper established the need for a new tool to measure the state of conservation of the historic built environment in Portugal, whilst proposing just such a tool – a model for evaluating the state of conservation of older buildings [1]. This model constitutes a comprehensive exercise in non-structural surveying, diagnosis and repairs balanced with regard to conservation principles - in a five-stage process as per Table 1.

The purpose of this paper is to advance the presentation of this model, albeit only to a limited extent, outlining its effectiveness in identifying the causes of anomalies in building walls. Whilst the model conceives of buildings in their entirety when considering strategies for intervention, for data collection purposes it divides the structure into individual components walls, ceilings, flooring, roofs and terraces – diagnosing causes of anomalies and planning for repairs with regard to each component, but bringing these together in the final stages to construct an integrated repair plan to respond to the anomalies and contextual constraints for the building as a whole. This paper therefore does not seek to present the whole process but focuses on the effectiveness of the model's implementation in stages 1-3 of the model in particular in real life case studies.

Additionally, one of the outcomes of our previous paper was the initial model's potential difficulties in responding to more recent structures, and older structures that had undergone substantial changes and reinforcement with newer materials during the course of their lifetimes. Therefore, whilst outlining the results of empirical testing of the model with regard to walls, we also apply it to buildings characteristic of a variety of constructive epochs.

TABLE I: Stages of the Proposed Model

1) Background work	Understand the context and important characteristics of the building.
2) Inspection	Visual analysis and identification of anomalies.
3) Diagnosis	Classification of pathologies using "anomaly-probable causes" correlation matrix.
4) Repair Planning	Outline potential repair scenarios, to include: • Preventive rehabilitation techniques (pr) • Remedial rehabilitation techniques (rr) • Maintenance work (m) • Reinforcement techniques (rf)
5) Repair in the context of conserving and enhancing heritage value	Unless unavoidable to ensure the stability and safety of the structure, discount those repair scenarios which do not meet the following criteria: • respect the integrity/character of the building • conserve and/or enhance heritage value • involve minimal intrusion • new works are reversible • are compatible materially, functionally and aesthetically

2. Walls in Buildings in Continental Portugal

Walls in Portuguese buildings are constructed from a somewhat more limited palette of materials than may be found in other places, partly due to regulatory requirements and partly due to socio-cultural traditions. For example, whilst in other parts of Europe wooden construction is reasonably common, there is widespread suspicion and distrust of its efficacy as a structural material in Portugal [2]. Whilst there has been a resurgence in the use of earth-based materials (rammed earth and adobe) in some regions of Portugal, exterior wall construction nevertheless generally comprises masonry of the following types: 1) Stone masonry (dry stone, or pointed/mortar set), either 1a) Ordinary/rough stone, or 1b) Cut stone; 2) Red brick (ceramic); 3) Simple concrete blockwork; 4) Cellular concrete blockwork; or 5) Expanded clay blockwork.

The majority of buildings in residential use today are constructed from the above materials, with their usage varying in predominance corresponding with different periods of construction. In Portugal, drawing from the work of Pinho [3] and Oliveira & Cabrita [4], we can to a large extent classify constructive epochs as per the categories presented below. Of course, such a classification is most relevant the urban centres, and particularly to Lisbon, where historically greater attention and enforcement of regulatory codes, in part responsible for the epistemic changes in construction at key points in history, were better managed and implemented. However, these categories can be found, albeit with some substantial local variations, throughout the country as a whole.

Category 1: Pre-earthquake masonry buildings (pre-1755). Sample size n=3 | Map colour: red. Stone masonry buildings comprise a combination of one or more materials, joined using mortar as a binding agent or, in some cases, joined under their own weight to be able to function under compression [5]. The most common stone types used in the north and interior of Portugal are, variously, granite and schist, whereas in Lisbon, the coast and the Alentejo there is predominance of limestone and brick [3], with some earth-based construction still observed in the Alentejo and the Algarve. In Lisbon, two main types of masonry construction from this period remain, including 1) grander buildings of three or four storeys of cut and carved stone with bracing; and 2) smaller rough masonry buildings with thick walls and few openings [4].

Category 2: "Pombaline" type post-earthquake masonry buildings or similar (1755-1880). Sample size n=4 | Map colour: white. Perhaps the most iconic of Portuguese constructions, the "Gaiola Pombalina" emerged as a response to the devastating 1755 earthquake. Designed by the miliary engineer Manuel da Maia, this system comprised a wooden "cage" with continuous joins bracing the structure in the form of a St Andrew's cross, which was infilled with masonry. The ground floor was slightly differently constructed, benefitting from ceramic or stone arches or domes [4].

Category 3: "Gaioleiro" type masonry buildings (1880-1930). Sample size n=2 | Map colour: yellow. With the memory of the earthquake long past, and the ever-present desire for reducing costs in a context of more limited resources, the "gaioleiro" building became common around the turn of the twentieth century. These were generally built higher, but with thinner walls of lower quality simple stone masonry, without bracing.

Category 4: Mixed stone masonry and concrete buildings (1930-1940). Sample size n=2 | Map colour: green. This category, commonly referred to as "placa" buildings, emerged from the 1930 General Regulation for Urban Construction, initially implemented in Lisbon but subsequently found across Continental Portugal. This advised the use of reinforced concrete as a bracing mechanism for buildings in the absence of the effective "Gaiola Pombalina" [6]. However, in some cases there were issues reconciling the weight of concrete slabs with the ability of finer walls to support them.

Category 5: Concrete buildings with stone masonry elements (1940-1960). Sample size n=4 | Map colour: blue. With the increasing popularity of concrete, low rise "confined" concrete frame buildings became increasingly common in this period, usually infilled with stone masonry, industrially produced ceramic brick or with concrete blocks. During this period, and often due to the good physical resistance offered by reinforced concrete, the thickness of external walls became increasingly shallow which, whilst saving costs, reduced resistance to the elements and, particularly, thermal and acoustic resistance.[5].

Category 6: Reinforced concrete buildings (post-1960). Sample size n=5 | Map colour: purple. With advances in technology and experience in using reinforced concrete frame (confined) structures, buildings became larger in terms of bulk and height. Such constructions became the default in Portugal and were made to offer sufficient resistance and resilience in response to an increasingly regulated construction sector.

As noted in the previous publication, the current methodology was designed to address the state of conservation of older buildings, which would typically have been built with stone masonry walls. However, the reality of housing stock in Continental Portugal is that it has usually been heavily modified over time, with many buildings demonstrating constructive elements and additions from several of the categories outlined above. It is therefore a useful exercise to test this model on a range of buildings constructed in and with typical characteristics of each of the different epochs categorised above to see if the model is sufficiently fit for purpose.

There are several ways to classify anomalies and pathologies in buildings and structures, and there have been many advancements in classificatory systems for masonry walls over the past few years. Such classifications are not limited to the overall performance of walls themselves, but also include their coverings and renders [7][8][9][10], and even paintwork, ceramic tiles and stone cladding [11][12][13]. The classificatory system proposed by [14] was taken as a basis for the model. Given the overall aim of this project is not only to establish a comprehensive methodology for the evaluation of the state of conservation of buildings but, in doing so, make it as user friendly and intuitive as possible, the categories were refined, redefined and redistributed in light of the literature above and empirical work to constitute the basis of the "walls" component of the tool through which the condition of the of the samples could be assessed according to the anomalies outlined in Table II.

TABLE II: Classificatory system for anomalies in masonry walls

A-A. OVERALL PERFORMANCE OF THE WALL	**A-B. COATING SYSTEM**
A-A.1 cracking	**A-B.1** cracking
A-A.2 crushing	**A-B.2** loss of cohesion / spalling
A-A.3 bulging	**A-B.3** loss of adherence
A-A.4 deterioration of mechanical characteristics	**A-B.4** efflorescence / cryptoflorescence
A-A.5 problems relating to thermal comfort	**A-B.5** presence of microorganisms / living organisms
A-A.6 problems relating to acoustic comfort	**A-B.6** blistering
	A-B.7 marks
	A-B.8 gaps/holes

Applying the model in practice, we draw here on a representative sample of n=20 case studies, distributed broadly evenly between the different epochs of construction.

3. Geographical Context of This Study

Each building was subjected to a systematic visual analysis, accompanied by some limited non-destructive surveys. Anomalies observed relating to the walls and their coating systems were collected as part of overall condition surveys, presenting an indicative snapshot of the condition of the walls of each building at the time of the inspections (undertaken in the period June 2020-June 2023).

As can be seen in the maps (Figures 1 and 2), the model was tested in buildings of diverse ages and types across much of Continental Portugal. There is no particular correlation between age of dwellings and location, with the exception of the cluster of newer dwellings between Caldas da Rainha and the coast as an area of rapid development over during this century. Some key differences, however, in geographical terms are climatic variations, and types of stonework used varying in different regions due to local availability [15]. In these samples, ordinary stonework is almost entirely limestone in older buildings due to the principal sources of extraction for this stone being in large quarries around Lisbon and in Leiria district (*Serras de Aire e Candeeiros*). The exception to this is in Coimbra district, where schist was used in early buildings.

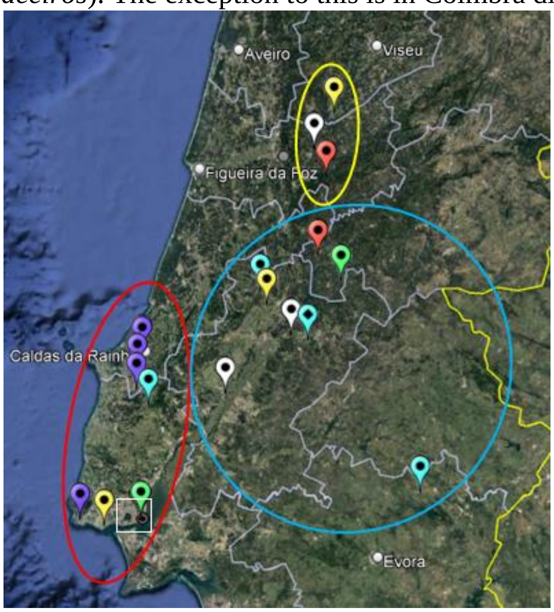

Fig. 1 Map showing the distribution of case study sample sites. These are colour classified by epoch of construction (see above), and by climate zone.

Fig. 2 Inset map showing case study sample sites in the City of Lisbon.

Climatically, coastal locations, shown in the red circled area, experience mild summers and winters, but the maritime environment is prone to specific agents of degradation (e.g. chlorides). Further inland, shown in the blue circled area, summers are intense whilst winters are moderately harsh. Finally, in some upland areas in Coimbra and Viseu district circled in yellow, summers and winters are moderately intense. These climatic differences are taken into account when inspecting a dwelling located in any one of these areas since any anomalies or deleterious effects will be different for similar structures.

4. Diagnosis of Anomalies in Walls

Within this section, we address how the model performs against each subcategory on the list (see Table III) with a discussion of its effectiveness at diagnosis of observed anomalies and, where relevant, identifying principal causative factors.

Cracking is observed most frequently at the interface of different materials; in older buildings where internal and external walls join. Internal walls have traditionally been constructed of lathe (and plaster), either wholly of wood or in some cases of contained stone masonry. Whilst cracking at these interfaces is sometimes expected in the absence of correct joins, fastenings and wall ties, it is often the case that internal wooden elements have degraded due to biological decay, including woodworm and other agents caused by an increase in humidity in the environment or the application of surface treatments that do not allow for breathability. In our samples, it is rare to find a building without cracking in the wall itself in buildings of any epoch of construction, with 85 percent of all buildings surveyed experiencing this to a greater or lesser extent.

TABLE III: Percentage of study samples manifesting anomalies per category

A-A. OVERALL PERFORMANCE OF THE WALL	**Index of presence (category/epoch of construction)**						
	1	**2**	**3**	**4**	**5**	**6**	**ALL**
A-A.1 cracking	100%	50%	50%	100%	100%	100%	**85%**
A-A.2 crushing	0%	25%	0%	0%	0%	20%	**10%**
A-A.3 bulging	0%	50%	100%	50%	25%	20%	**35%**
A-A.4 deterioration of mechanical characteristics	33%	50%	0%	0%	0%	20%	**20%**
A-A.5 problems relating to thermal comfort	66%	50%	100%	50%	100%	60%	**70%**
A-A.6 problems relating to acoustic comfort	0%	0%	0%	50%	0%	0%	**5%**
A-B. COATING SYSTEM							
A-B.1 cracking	66%	75%	100%	100%	75%	100%	**85%**
A-B.2 loss of cohesion / spalling	33%	100%	0%	100%	50%	40%	**55%**
A-B.3 loss of adherence	33%	25%	50%	0%	50%	0%	**25%**
A-B.4 efflorescence / cryptoflorescence	100%	75%	100%	50%	100%	100%	**90%**
A-B.5 presence of microorganisms / living organisms	66%	75%	100%	50%	50%	60%	**65%**
A-B.6 blistering	66%	75%	50%	100%	75%	80%	**75%**
A-B.7 marks	66%	100%	100%	100%	75%	100%	**90%**
A-B.8 gaps/holes	0%	25%	0%	0%	25%	0%	**10%**

Crushing in masonry walls is not necessarily common since masonry is reasonably resilient to compressive stress [16]. Crushing, therefore, is indicative either of distortions in the wall caused by structural misalignments, or else simply resultant from degraded, missing or damaged masonry elements. This is only found in categories 2 ("Pombaline") and 6 (modern) resultant from, respectively, a substantial missing section of wall, and from highly degraded rebars in structural columns.

Bulging of walls appears to be associated most with category 3 ("gaioleiro") constructions. These buildings are associated with deficient quality in construction, in a context of a lack of availability of quality wooden elements in particular, and insufficient overall structural dimensioning, leading to regular failure of these buildings [3][6]. However, examples of bulging are observed in buildings in most of the other categories. In older buildings this is usually due to degradation and slippage of wooden wall inserts, whether structural joists of wooden cross pieces, due to moisture ingress; whilst in newer buildings bulging generally manifests at lower levels in the continued absence of damp proof layers, or is indicative of ruptures in plumbing systems.

The deterioration of mechanical characteristics is uncommon in newer buildings. In older buildings in our sample, it is associated with exposure of constructive elements to moisture variations. The breakdown of older masonry is sometimes but not often a result of any inherent problems in the masonry itself, but rather with subsequent interventions that have impeded the evaporation of water vapour/moisture from the interior to the exterior of the wall. This includes but is not limited to the repointing or rendering of brick or stonework with Portland cement mortars/renders, and the installation of cladding or use of non-breathable paint, which results in trapped moisture rotting more porous stone.

Issues of deficiency in thermal comfort are present in dwellings of all ages. Improvements in regulation have only been recent, with requirements for the installation of thermal insulation in new builds introduced in 2006, more comprehensively in 2013 (Decree-Law n.º 118/2013), and reinforced in 2020 (Decree-Law n.º 101-D/2020, and Portaria n.º 138-I/2021). None of the buildings included in the sample, therefore, were constructed after the 2013 regulations came into force. Given that thermal inertia to a large extent depends on heat transfer through materials, generally the thicker the wall, the more effective its thermal insulation. It follows that thicker walls (circa 80cm) in many of the older buildings surveyed would offer very effective insulating properties. They do so, with the exception of window bays present in most of the older buildings in the sample, where in some cases the thickness of the wall falls to circa 20cm, thus constituting thermal bridges.

Conversely, most samples did not suffer from deficiencies in acoustic insulation. Whilst acoustic comfort to an extent depends upon many of the same factors as thermal insulation, the key difference is the presence of a noise source in relation to the receptor. We can concede that the design and specification of the original construction most likely would have considered the potential for noise trespass at the time of construction. In most cases, with the key exception of dwellings located in the Lisbon urban area, these sources have not increased in the meantime, and the walls resist noise transfer.

With regard to coating system categories, render deterioration is often a natural attribute of this layer since this is a sacrificial layer [3], but it should not crack, particularly over the short term and in newer construction. Often such cracking is due to inadequate preparation of render (e.g. excessive moisture) or execution conditions (e.g. high temperatures leading to the render drying too quickly). In other cases, in both older and newer buildings, insufficient attention is given to compatibility of new render with existing, with cracking at the interface between old and new render is problematic.

Over the course of a building’s lifetime, without adequate and regular maintenance, traditional coatings (including render, marmorite pebbledash, tile or others) are likely to degrade and spall, with loss of cohesion and of adherence, with constant exposure to the elements and through the action of some biological agents. A difference with more modern buildings and their reliance on reinforced concrete is that spalling of material can indicate different and potentially more significant structural problems, most commonly the corrosion of rebars embedded in structural elements.

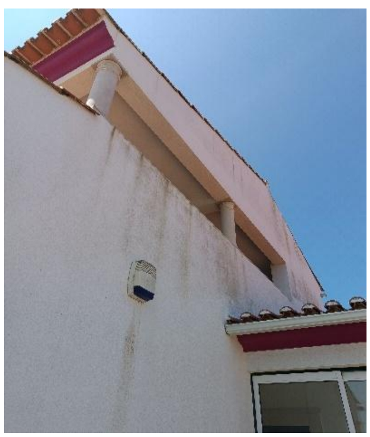

Fig. 3 (left) and Fig. 4 (right) showing the impact of moisture damage and associated biological colonisation on poorly resolved and protected verges and parapets.

Unfortunately, and as per the diagnoses in Table IV, problems of poor design and implementation of regulations persist in Portuguese construction with regard to the distinct yet interrelated phenomena of efflorescence, the presence of microorganisms, blistering, and other marks. These are present in buildings of all ages and construction types. Manifestations are indicative of a lack of resistance to moisture (damage) of the building envelope through the lack of damp proof courses, not to be expected in older buildings but advisable for newer dwellings, resulting in rising damp via capillary action. Combined with an inconsistent approach to guttering allowing rainwater to splash back onto walls and, finally, almost universally a deficiency in internal ventilation, avoidable or mitigatable degradation to walls occurs. More recently, these phenomena have been exacerbated due to an architectural trend towards shallow verges (often on gable end walls) and uncapped horizontal parapets (Figures 3 and 4).

Notwithstanding the variations in sample sizes between the different epochs, we can appreciate that there are clear commonalities and differences in the types and causes of anomalies between them in Table IV. In this table, only those anomalies identified as being present in our samples have been included, with particularly high values shaded in grey in the individual category columns, or amber in the final category, to indicate the most commonly observed anomalies. Environmental and biological agents of degradation are revealed by the model to be the most problematic. Among these, by far the most deleterious are problems caused by moisture variations, creating conditions for the rapid degradation of wood, metal, mortars and, in the case of porous masonry with inadequate ventilation, the disintegration of stonework. This is exacerbated by a lack of or damaged guttering and rainwater drainage infrastructure, which is still not universal in Continental Portugal, meaning that walls can suffer unduly from roof runoff.

TABLE IV: Index of the instances of diagnosis of each causative factor (per building age category)

	1	**2**	**3**	**4**	**5**	**6**	**ALL**
C-A. PROJECT ERRORS							
C-A.9 absent/insufficient thermal insulation	4	1	5	2	7	9	**28**
C-A.10 absent/insufficient ventilation	3	2	2	3	6	9	**25**
C-A.13 poor specifications	1	9	2	2	10	0	**24**
C-B. EXECUTION ERRORS							
C-B.13 incorrect assembly/ installation of windows	0	6	0	1	0	0	**7**
C-B.18 poor execution of water distribution and rainwater drainage networks	1	7	0	1	3	9	**21**
C-C. ENVIRONMENTAL / BIOLOGICAL ACTION							
C-C.1 thermal variations	0	5	2	5	5	8	**25**
C-C.2 rain	6	8	5	4	5	4	**32**
C-C.3 moisture variations	4	14	4	7	10	24	**63**
C-C.7 biological action	2	5	1	1	3	8	**20**
C-D. HUMAN / MECHANICAL ACTION							
C-D.3 lack of or inappropriate maintenance	0	3	0	2	2	9	**16**
C-E. MAINTENANCE PROBLEMS							
C-E.4 insufficient indoor ventilation	2	4	0	2	2	9	**19**
C-E.5 low indoor temperature	1	1	0	2	1	9	**14**
C-E.6 lack of cleaning/maintenance of surface	4	3	3	0	3	12	**25**

One interesting characteristic of more recent (category 6) buildings is the relative lack of general cleaning and maintenance they appear to receive in comparison with older buildings. This raises some sociological issues as to the ways in which we now live in our homes, and domestic work, including general cleaning and maintenance, become relegated to being secondary concerns, highlighted particularly in this small sample in modern properties. Whilst further investigation into such a hypothesis is beyond the scope of this paper and, indeed, of this project, this could have major implications for the longevity/life span of individual constructive components.

5. Conclusion

It has been demonstrated in this paper that the model as proposed is effective at analysing the causes of anomalies in building walls. This is not only the case for older buildings for which the tool was originally designed, but for buildings constructed and/or having undergone extensive interventions in each of the distinct epochs commonly defined for Portuguese construction up to the present day. However, the sample size was necessarily limited in the current phase, and particularly for some building periods where there was more limited opportunity to inspect.

The model highlights the main causes of degradation of walls in the national building stock as related to their insufficient resistance to moisture ingress and insufficient breathability of walls resulting in biological decay in all buildings, and chemical decay particularly in newer buildings. It suggests that this can be attributed to three main deficiencies, including a lack of internal ventilation, and a lack of integrated rainwater drainage and guttering in all buildings. Also. poorly designed window openings and the retrofitting of newer windows into older openings have often been done poorly in older buildings leading to problems in and around these elements.

Finally, it was observed that there is a slightly higher tendency for a lack of cleaning and maintenance in newer buildings. The causes of this merit further consideration since it can result in failure of constructive elements, compromising comfort and possibly safety of the occupants, and resulting in shorter building lifespans.

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