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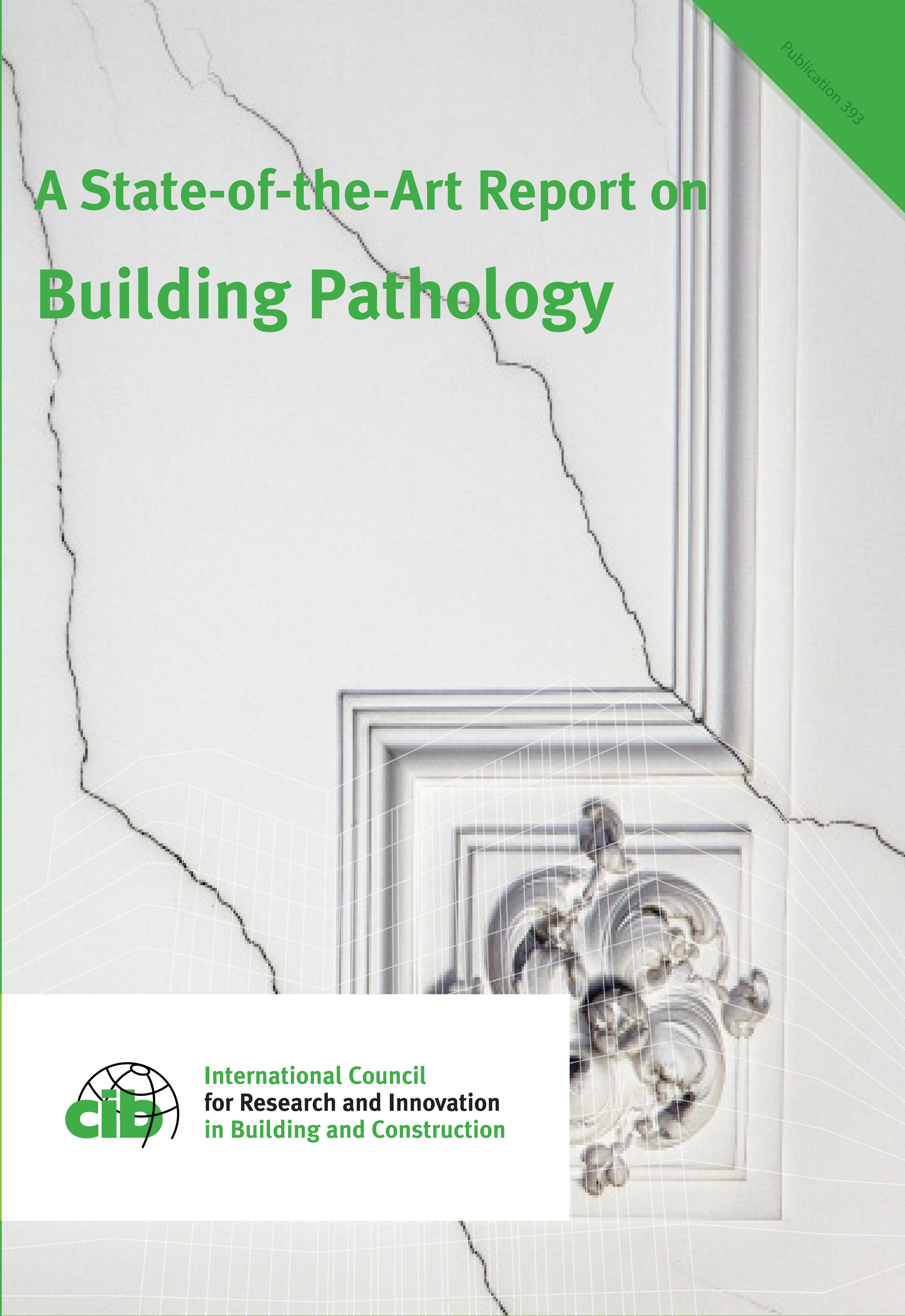
A State-of-the-Art Report on Building Pathology



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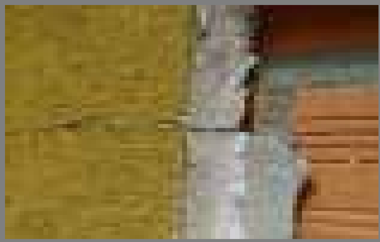

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CIB – W086
BUILDING PATHOLOGY

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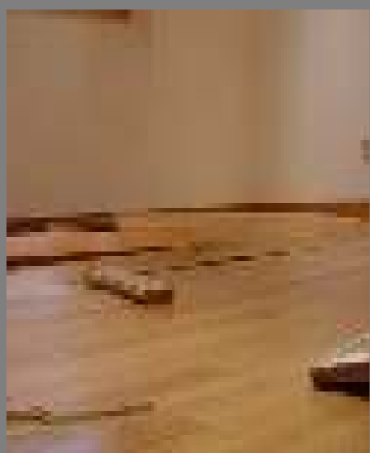
VASCO PEIXOTO DE FREITAS



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2013

COORDINATORS

Vasco Peixoto de Freitas	Portugal
Enrico de Angelis	Italy

AUTHORS

Ana Sofia Guimarães	Portugal
Albina Scioti	Italy
Antonella Guida	Italy
Antonello Pagliuca	Italy
Atilla Koppány	Hungary
Bill Porteous	New Zealand
César Díaz Gómez	Spain
Clara Liaño	Spain
Eva Barreira	Portugal
Fabio Fatiguso	Italy
Filiberto Lembo	Italy
Francesco Marino	Italy
Giambatista De Tommasi	Italy
Ippolita Mecca	Italy
Inês Flores-Colen	Portugal
Isabel Torres	Portugal
Ignacio Lombillo	Spain
Joan Lluis Zamora	Spain
Josifas Parasonis	Lithuania
Jorge de Brito	Portugal
J. Mendes da Silva	Portugal
Luis Villegas	Spain
Mariella De Fino	Italy
Miguel Vieira	Portugal
Pedro Lima Gaspar	Portugal
Romeu Vicente	Portugal
Sara Stingl de Freitas	Portugal
Sergio Croce	Italy
Vasco Peixoto de Freitas	Portugal
Vitor Cóias	Portugal

CONTACT ADDRESS

Vasco Peixoto de Freitas
Building Physics Laboratory – LFC
Porto University-Faculty of Engineering
Rua Dr. Roberto Frias, 4200-465 Porto, Portugal
Phone: +351 225 081 478
E-mail: lfc-scc@fe.up.pt
Web: http://www.fe.up.pt/~lfc-scc

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LFC – Building Physics Laboratory

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Ana Stingl

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PREFACE

The CIB W086 – Building Pathology Commission is basically concerned with learning from past and current building pathologies and encouraging the systematic application of that knowledge to the design, construction and management of buildings.

Building pathology provides a systematic scientific approach to discovering what has gone wrong in a failed building. The objectivity it brings to bear helps to make an investigation independent of prejudice and of matters of blame. The building pathologist is concerned with what has happened and how it came to happen, rather than with attributing blame. The pathologist's approach is to ascertain facts rather than to attribute liability. Any investigation of building failure carried out solely for the purposes of attributing blame, as distinct from attributing cause, is at risk of being subverted by legal considerations of liability (B. Porteous).

This publication "State of the Art Report on Building Pathology" aims to be a concise document that binds a set of in-depth articles. A short introduction is provided in Chapter 1 to present the CIB W086 – Building Pathology Commission and to summarize its recent activities. Chapter 2 deals with Building Pathology and Costs, while Chapter 3 presents the Research Methodology. Chapter 4 describes the Information Dissemination, and Chapter 5 is devoted to special Case Studies, where some practical examples are explained. Finally, Chapter 6 and 7 provide, respectively, the most important conclusions and the lists of reference documents.

The document has been prepared with the contribution of a large group of members of CIB: EDITOR -Vasco Peixoto de Freitas (Portugal) AUTHORS -Ana Sofia Guimarães (Portugal), Albina Scioti (Italy), Antonella Guida (Italy), Antonello Pagliuca (Italy), Atilla Koppány (Hungary), Bill Porteous (New Zealand), César Diaz (Spain), Clara Liaño (Spain), Enrico de Angelis (Italy), Eva Barreira (Portugal), Fabio Fatiguso (Italy), Filiberto Lembo (Italy), Francesco Marino (Italy), Giambatista de Tommasi (Italy), Ippolita Mecca (Italy), Inês Flores- Colen (Portugal), Isabel Torres (Portugal),Ignacio Lombillo (Spain), Joan Lluis Zamora (Spain), Josifas Parasonis (Lithuania), Jorge de Brito (Portugal), J. Mendes da Silva (Portugal), Luis Villegas (Spain), Mariella de Fino (Italy), Miguel Vieira (Portugal), Pedro Lima Gaspar (Portugal), Romeu Vicente (Portugal), Sara Stingl de Freitas (Portugal), Sergio Croce (Italy), Vasco Peixoto de Freitas (Portugal) and Vitor Cóias (Portugal).

This "State-of-the-art report" on Building Pathology pretends to be a contribution to the systematization of information offered by W086 commission with free access to the site to all stakeholders. The Editorial Board, founded by experts in the field of buildings pathology, constitutes the foundation for a quality job that we want to perform. We take the opportunity to thank the colleagues that contributed to the elaboration of this publication. It was an indispensable work with high quality and importance.

We have conscience that has a lot of work to do with the goal of decrease building pathology or diagnose it correctly. Although, we hope that this "State-of-the-art report" could be a small but an important contribution.

Vasco Peixoto de Freitas

CONTENTS

CHAPTER 1

INTRODUCTION

1.1 THE CIB W086 – BUILDING PATHOLOGY COMMISSION

(Vasco Peixoto de Freitas and Enrico de Angelis)

CIB is the acronym of the INTERNATIONAL COUNCIL FOR RESEARCH AND INNOVATION IN BUILDING AND CONSTRUCTION. CIB was established in 1953 in order to stimulate and facilitate international cooperation and information exchange between government research institutes in the building and construction sector, with an emphasis on those engaged in technical fields of research.

CIB has since evolved into a worldwide network of over 5000 experts from about 500 member organizations with research, university, industrial or governmental background, who collectively are active in all aspects of research and innovation for building and construction. A CIB Commission is a worldwide network of experts in a specific scientific area who meet regularly and exchange information on a voluntary basis.

Most Commissions have one Coordinator, who is appointed by its members and by the CIB Programme Committee. W086 – Building Pathology has two Joint Coordinators: Prof. Vasco Peixoto de Freitas from the Faculty of Engineering, University of Porto, Portugal and Prof. Enrico de Angelis from the Polytechnic of Milan, Italy.

The previous coordinators of the CIB W086 were Arie van den Beukel, TNO, The Netherlands; Peter Trotman, Building Research Establishment, UK; Bill Porteous, Victoria University of Wellington, New Zealand and Sergio Groce, Polytechnic of Milan, Italy.

The CIB W086 commission usually holds annual plenary meetings, organized by a CIB member organization represented within the Commission. It also holds regular international symposiums, conferences and workshops.

1.2 ACTIVITIES OF CIB W086 – BUILDING PATHOLOGY

The scope, objectives and work programme of each Commission are defined by its members and officially approved by the CIB Programme Committee. Detailed information about the W086 commision (Scope, Membership, Publications and last Meetings) are presented below.

1.2.1 SCOPE

The W086 commision is basically concerned with learning from past and current building pathologies and encouraging the systematic application of that knowledge to the design, construction and management of buildings. Researchers are invited to present their work at the meetings, where the information is discussed and then distributed around the participants' institutions and countries.

Hence, the objectives of CIB W086 are:

- To produce information which will assist in the effective management of service loss;
- To develop and evaluate methodologies for the assessment of defects and failures and consequential service loss;
- To propose methodologies for the prevention and mitigation of building defects;
- To analyze costs associated with building pathology
- To promulgate findings to all those involved in the production and management of buildings.

1.2.2 MEMBERS

The W086 commission has, at the moment, almost 50 members from Australia, Brazil, Canada, Denmark, Hungary, India, Ireland, Italy, Japan, Lithuania, Netherlands, Portugal, Romania, Singapore, Slovakia, Spain, Turkey and the United Kingdom.

Members of this Working Commission have to be either a representative of a CIB Member Organisation or an Individual CIB Member. They are elected by the working party at the ordinary meetings. All members must participate actively in W086's meetings, present their own research and take part in discussions. In addition, members must provide information on the work of W086 in their home countries and also keep W086 informed of current research in those countries.

1.3 PUBLICATIONS

Its most recent publications are as follows:

Year	Title	Type of Publication
2010	Collected Papers on Building Technology, 18th CIB World Building Congress, May 2010, Salford, UK	Proceedings
2006	Construction in the 21st Century: Local and Global Challenges, Milan, Italy	Proceedings
2003	2nd International Symposium on Building Pathology Durability and Rehabilitation, Lisbon, Portugal	Proceedings
1993	Building Pathology – CIB report 155	Report

1.4 MEETINGS/CONFERENCES

Since 1997, the CIB W086 commission held the following meetings/conferences in different places all over the world:

Year	Event	Location
2010 October	CIB W086 annual meeting on Building Pathology, in conjunction with the 37th IAHS World Congress on Housing Science	Spain Santander
2010 May	CIB Working Commission Meeting on Building Pathology, in conjunction with the 18th CIB World Building Congress	U. K. Manchester
2009 March	CIB W086 annual meeting on Building Pathology, in conjunction with the Conference PATORREB 2009	Portugal Porto
2008 May	CIB W086 annual meeting on Building Pathology, in conjunction 11th DBMC Conference	Turkey Istanbul
2006 October	CIB W086 annual meeting on Building Pathology, in conjunction with the International CIB Symposium: Construction in the 21st Century - Local and Global Challenge	Italy Rome
2005 April	CIB W086 annual meeting on Building Pathology, in conjunction with the 10th DBMC - International Conference on Durability of Building Materials and Components	France Lyon
2003 November	CIB W086 annual meeting on Building Pathology, in conjunction with the 2nd International Symposium on Building Pathology, Durability and Rehabilitation "Learning from Errors and Defects in Building"	Portugal Lisbon
2001 April	Workshop on Building Pathology, in conjunction with 15th CIB World Building Congress	New-Zealand Wellington
2000 June	CIB W086 annual meeting on Building Pathology	Portugal Lisbon
2000 June	Workshop on Building Pathology and Design for Durability	Portugal Lisbon
1999 May	CIB W086 annual meeting on Building Pathology, in conjunction with 8th DBMC	Canada Vancouver
1998 June	CIB Commission Meeting on Building Pathology in conjunction with the 14th CIB World Building Congress	Sweden Gävle
1997 June	CIB Commission Meeting on Building Pathology	United Kingdom Oxford

CHAPTER 2

BUILDING PATHOLOGY AND COSTS

2.1 THE IMPORTANCE OF BUILDING PATHOLOGY

(Bill Porteous)

2.1.1 INTRODUCTION

It is a truism, but one that is often overlooked, that every building is a prototype. There are no two identical buildings in the world. That is because there is so much opportunity for variation (and error) in the thousands of actions that are taken in constructing a building, and in the circumstances in which those actions are taken.

Examples of such variations are the ambient weather conditions, which can affect the curing of concrete or coatings, or the decision to substitute one seemingly, but not actually identical product for another. The first of these examples may lead to different degrees of cracking or powdery finish in the concrete or coatings of otherwise apparently identical buildings. The second of these examples may lead to different patterns of corrosion because the substituted stainless steel fastenings are not of the same grade as those specified and react adversely with the stainless steel panels they have been used to fasten in place.

Given that all buildings are prototypes, and the results of so many variations in the sequence of actions that create them, it is not surprising that investigation of buildings that have failed is often seen as more analogous to medical diagnosis than to investigation of an inoperative machine. Because the diagnosis of building failures is not carried out on living things, but rather on inanimate ones, the term building failure has been adopted [Porteous 1985].

2.1.2 HOW USEFUL IS BUILDING PATHOLOGY?

Building pathology is arguably as useful to the science and practice of building as medical pathology is to the science and practice of medicine. The main benefits of the practice of building pathology are as follows:

2.1.2.1 SYSTEMATIC SCIENTIFIC APPROACH

Building pathology provides a systematic scientific approach to discovering what has gone wrong in a failed building. The objectivity it brings to bear helps to make an investigation independent of prejudice and of matters of blame. The building pathologist is concerned with what has happened and how it came to happen, rather than with attributing blame. The pathologist's approach is to ascertain facts rather than to attribute liability. Any investigation of building failure carried out solely for the purposes of attributing blame, as distinct from attributing cause, is at risk of being subverted by legal considerations of liability.

2.1.2.2 POSSIBLE DETECTION OF TRENDS AND PATTERNS

Building pathology investigations carried out on a large enough sample of buildings will reveal patterns of building failure by identifying the common features of buildings that have failed. If such investigations are carried out over an extended time, trends in failure type and frequency may be detected. For best results it is important that a systematic approach to the classification of failures, their features and their causes is used [Porteous 1992].

2.1.2.3 OBTAINING EMPIRICAL EVIDENCE

Building pathology provides convincing evidence because it involves buildings that have actually been constructed and are being tested in use in a real world environment, rather than being tested or modeled in a laboratory or computer simulation. The inadequacies of such testing, modeling and simulation are thus avoided. Such inadequacies include the inability of many testing and modeling systems to replicate the capricious nature of the weather, and of human behavior in buildings, the variability of workmanship between buildings, and the differences between what is shown on plans and what has actually been built.

2.1.3 CONSEQUENCES OF APPLYING BUILDING PATHOLOGY?

There are other desirable consequences of applying the practices of building pathology to the investigation of building failures. Some of these can be described as follows:

2.1.3.1 AVOIDANCE OF SUPERFICIAL JUDGEMENT

A person mindful of building pathology will be much more inclined to select and use building materials and techniques with a view to the performance of those materials and techniques over time. For example, instead of being influenced largely or solely by the appearance or tactile properties of a material, or even by persuasive advertising, building pathology requires consideration of maintenance requirements, durability, suitability for purpose, compatibility with other materials and the like.

This approach contrasts with the superficial unscientific assessment of building failures that occurs in the popular press. The superficial approach makes no attempt to establish the root causes of building failures or to distinguish between human errors and materials failure. Thus the cracking failure of a brick building will be blamed on the bricks, and no thought given to the possibility of under-designed foundations, expansive-clay soils, or the possibility that defective cement may have unwittingly been used in the mortar. In New Zealand in recent years it has not been unknown for leaking buildings to be attributed to the use of untreated timber wall framing. While it is true that such timber suffers from decay in a leaking building it is clearly illogical for journalists to suggest that it is the timber that causes the leaking. A person with some understanding of the building pathologist's approach to building failures would not draw such an unscientific conclusion.

2.1.3.2 BETTER DESIGN (AND SELECTION) TO AVOID FAILURES

Knowledge of the way buildings and their component materials have performed in the past can contribute to avoidance of repeated errors and better selection of materials and components for given design applications. Experience of seeing certain designs fail for reasons of poor detailing of the assembly or inappropriate choice of materials will make building pathologists very sensitive to careful design of similar features in the future.

For example, research by Clark [Clark 2008] has shown, by systematic analysis, that certain cladding materials and techniques are less tolerant of misuse than others. They require closer attention to manufacturers' recommendations than some other materials and techniques that perform much the same functions once in place. It would be wrong to condemn such cladding materials and techniques when, used carefully, they can perform well.

2.1.3.3 DEVELOPMENT OF BETTER MATERIALS AND SPECIFICATIONS

Flowing from 2.1.3.1 and 2.1.3.2 above will be the development of better approaches to the design, specification and construction of buildings. In this context 'better' means more reliable, more durable, requiring less maintenance, and still serving its purpose well. These developments do not need to be to the detriment of elegant aesthetic design but may actually add to the quality of those designs by emphasizing the fit for purpose, easy and pleasant to use (and maintain) aspects of fine building design.

One of the notable features of great buildings tends to be the way in which they age, gathering a patina from continual use and wear that matures the building without damaging it. Well-chosen materials and design features make an important contribution to that process, and help to ensure that fine buildings last for generations because they employ materials, components and designs that do not require frequent and expensive maintenance.

2.1.4 CONCLUSIONS

Building pathology is as important to the science of building as medical pathology is important to the science of medicine.

Building pathology provides the opportunity to dispassionately observe in detail what has gone wrong with a building and to provide guidance to prevent as well as to repair [Porteous 1994].

The obvious difference is that knowledge gained from building pathology experience can be applied to improve the design and performance of future buildings. Knowledge gained from medical pathology cannot be applied to improvement in the design of the human body, although it can be applied to better maintenance of future human bodies.

It is the systematic and repeatable application of building pathology principles that makes their use so valuable.

2.1.5 REFERENCES

Clark, S. 2008. *Building envelope characteristics and associated weathertightness defects*. Report to the Department of Building and Housing (New Zealand) on the results of a study of 408 weathertightness determinations.

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2.2 BUILDING PATHOLOGY RELATED COSTS

(Vítor Cóias)

2.2.1 INTRODUCTION

Building pathology has been defined in CIB Publication 155 (the State-of-the-Art Report now being the object of updating) as *the systematic treatment of building defects, their causes, their consequences and their remedies.*

According to Euroconstruct, building construction accounts for 80% of all investments in the construction industry in the 15 organization's WESTERN European countries and for 64% in the 4 Eastern Europe ones [Euroconstruct 2011]. Investment in residential construction alone amounts to nearly 600 billion Euros (600 000 million Euros). Total investment in construction amounts to around twice that figure, representing more than 10% of the total GDP of the 19 Euroconstruct countries (around 12 700 billion Euros). Total investment in building construction (residential and non-residential) amounts to 1 000 billion Euros. Taking into account that building failure costs (costs ascribed to building defects and imperfect control of the building process) amount to around 5 to 10% of production costs [CIB W086 1993, Beukel 1994, Ingvaldsen & Thorbjørn 1994, Lichtenberg 2006], they add up, in Europe, to between 50 and 100 billion Euros.

By and large, according to Euroconstruct figures, around 55% of all building production (i.e. around 544 billion Euros) is channeled to building renovation and rehabilitation in the 19 Euroconstruct countries. Building renovation (or refurbishment) is a broader concept that covers a wider scope than rehabilitation. Both activities are methodologically and technologically more complex than new construction, therefore more prone to defects.

Extravagant architecture or recent trends like green building design may be sources of additional defects [Angelo 2007, Tulacz 2008].

Building defects, the basic elements of building pathology, are defined in reference to levels of performance of the building or its parts. According to ISO15686-1:*2000(E), a "Defect" is a fault, or deviation from the intended level of performance of a building or its parts.*

The levels of performance vary widely from case to case, but can be related to the seven essential requirements of Regulation (EU) No. 305/2011 of the European Parliament and of the Council of 9 March 2011 (the Construction Products Regulation):

1. Mechanical resistance and stability;
2. Safety in case of fire;
3. Hygiene, health and the environment;
4. Safety and accessibility in use;
5. Protection against noise;
6. Energy economy and heat retention;
7. Sustainable use of material resources.

As these requirements are translated into the codes and regulations applicable to buildings, lack of compliance with them brings to light, in broad terms, another set of deficiencies and, therefore, gives rise to building pathology-related costs.

The need to promote the sustainable use of the building stock brings social and environmental considerations into play, together with economic ones. As a result, the life expectancy of buildings tends to be extended, and the levels of essential requirements mentioned above tend to become more stringent, particularly with regard to energy and environmental performance.

With only 1% to 2% of Europe's building stock being replaced annually, building deterioration and obsolescence grow, increasing building stock management costs.

2.2.2 BUILDING PATHOLOGY AND LIFE CYCLE COSTS

Life cycle costs can be defined as *the total cost of a building or its parts throughout its life, including the costs of planning, design, acquisition, operation, maintenance and disposal, less any residual value.* [ISO15686-1:2000(E)]. The building's life cycle can be broken down in two stages, figure 1: the initial stage of conception, design and construction, up to the warranty termination, hereafter designated as "construction stage", and the period from there to building's decommissioning and disposal, hereafter named "running stage".

If all costs involving a building from conception to demolition are taken into account, the construction stage represents only 17% to 25% [Perret 1995]. The remaining nearly 80% are operation and maintenance-related costs, occurring in the running stage. Of that first part, only a small percentage, around 10% to 20%, is spent in planning, design (conceptual and detailed) and inspection, with the remaining 80% to 90% being spent on actual construction. This means that only around 2 - 5% of all costs involved in a building's construction and operation is spent on conception, design and supervision (Figure 2). However, the quality of the design is of paramount importance in reducing costs over the entire building's life cycle.

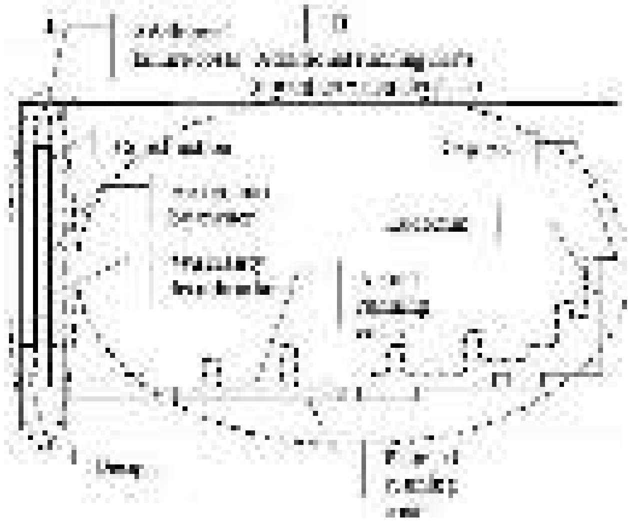

Figure 1 – Building's life cycle costs: Construction stage (I): Defect costs are in average roughly 3 to 5% of total construction costs. Running stage (II): a) Extra annual maintenance costs, caused by design or construction defects may be in the range of 1 to 2%. b) Extra annual (direct) operation costs, caused by design or construction defects may also be in the range of 1 to 2%.

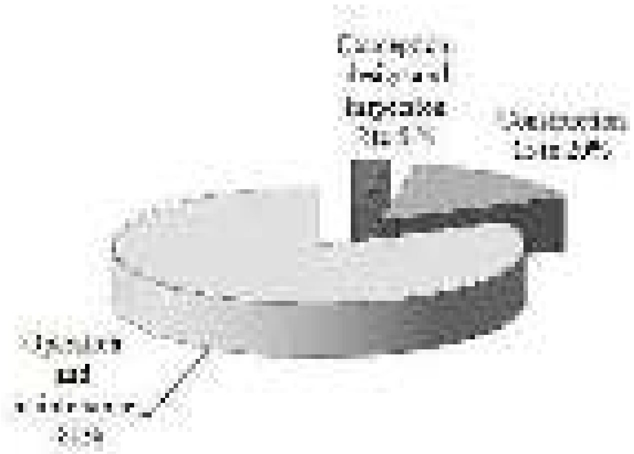

Figure 2 – Building's life cycle costs: Only around 2 to 5% of all costs involved in a building's construction and operation is spent on conception, design and supervision.

Keeping in mind the above definition, building pathology-related costs are those resulting from *the systematic treatment of building defects, the analysis of their causes and consequences and the remediation of their effects.*

In dealing with building defects and their consequences, the two main stages of the building´s life cycle should be considered: during the construction stage, defects prevent the building of reaching the intended level of performance, requiring corrective interventions; during the running stage, building defects accelerate the degradation of its condition, requiring more frequent or more extensive maintenance and aggravating operating costs. Following the quality management terminology, the costs incurred in the construction stage are termed "failure costs";Sticking to CIB Publication 155's definition of "rehabilitation", the costs due to interventions aimed at restoring the building's performance during the running stage, will be classified as defect-related "rehabilitation costs".

2.2.2.1 QUALITY COSTS

Through the end of the building's warranty period, building pathology-related costs can be classified as quality costs, which, according to the current quality cost model, are usually broken down into three parts: *prevention*, *appraisal* and *failure* costs. Of these three parts, failure costs are those, by definition, more directly related to building pathology, and will depend on the effectiveness of the quality management (Figure 3). Defect-related failure costs are broken down in "internal" and "external" if they result from defects occurring respectively before or after the Owner's acceptance of the building.

However, in addition to these *visible* failure costs, which can be determined on relatively simple objective criteria, a third category of failure costs, and thereby defect costs, should be taken into account: costs incurred by the contractor whose estimation resort to essentially subjective and unconventional criteria — *invisible* or *hidden* quality costs. In the construction sector, examples of hidden quality costs are schedule delays, litigation and claims, loss of reputation and the subsequent impact on future business opportunities, loss of productivity, idle time, etc. [Sellés et al. 2008]. One additional cost category could be considered, which stems from the increased risk of property damage or occupant injury. Examples of these *latent* costs are the liabilities related to faulty fire or earthquake design or execution.

2.2.2.2 REHABILITATION COSTS

Rehabilitation costs may be brought about by four main reasons:

a) To do away with defects and their consequences, in order to recover the building's level of performance;

b) To remedy accidental damage due to causes not pertaining to the building, with the same objective;

c) To make up for normal aging and wear and tear, again with the same objective;

d) To upgrade the building's performance, in order to ensure its compliance with more demanding requirements.

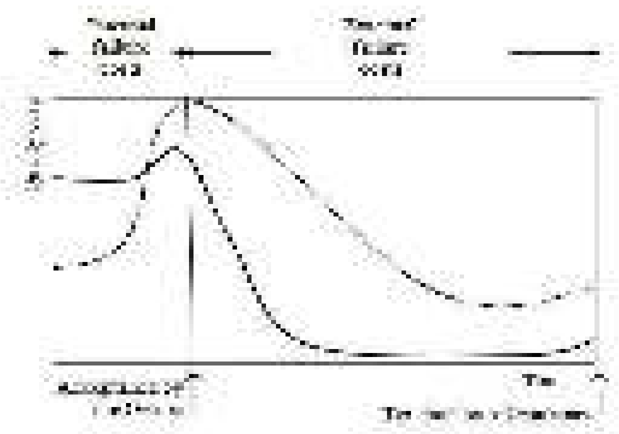

Figure 3 – Design and construction stage. Failure costs with (solid line) and without (dotted line) effective quality management.

In the first case, defect-related rehabilitation costs are, therefore, the expenses implied by defect correction after the building's warranty termination, including their contribution to its ensuing life cycle costs. In fact, design or construction defects may continue to require post-warranty interventions, adding to the building's running costs (Figure 3). Running costs are the sum of maintenance and operating costs, and both are impacted by defects.

In the second case the rehabilitation costs are related to building pathology, but they will not be considered due to their accidental nature. To be precise, however, the possible aggravating influence of defects upon the consequences of accidental actions should be kept in mind.

In the third case, the rehabilitation costs will not be taken into account, notwithstanding the possibility of precocious aging due to design or construction defects.

In the last case, further rehabilitation costs are incurred which, again, are not brought about by building defects and should not be considered as related to building pathology. These costs are mainly due to obsolescence and fall into a broader category that can be called renovation or refurbishment. However, there are still some additional costs that should also be considered as building pathology-related costs, as explained ahead.

Building pathology affects both new construction and rehabilitation projects, since rehabilitation work has its own life cycle and is subject to its own defects. Any rehabilitation work therefore implies a revision of the maintenance plan of the building and, as a result, of its maintenance costs.

2.2.2.3 OTHER BUILDING PATHOLOGY RELATED COSTS

Besides the above mentioned visible and hidden costs for the contractor, additional costs arising from building defects may be mentioned, weighing either on the owner, stakeholders or the sector:

- Distress caused to owner;
- Effect on insurance premiums;
- Effect on regulatory authorities;
- Implications on the reputation of professionals involved other than the contractor, such architects and engineers;
- Loss of confidence in the industry.

Moreover, additional social costs may be incurred from building defects, when they influence on occupants' health or cause accidents jeopardizing life and limb, either during the building's construction or operation.

Finally, design or construction defects can cause unforeseen environmental costs either during construction and running stages, such as material or energy waste, increased hazardous waste and toxic emissions, global warming or local urban climate degradation, compounded, particularly in the case of residences, by their disproportionate environmental impact relative to their share of economic activity [Ochoa et al. 2002].

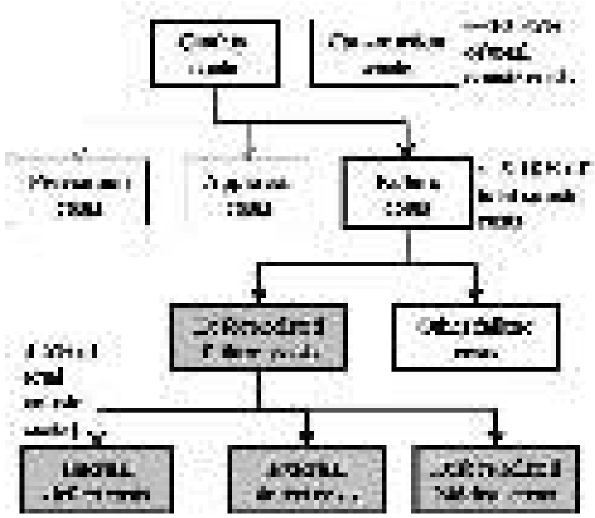

Figure 4 – Quality costs and pathology-related costs through warranty termination. Shaded rectangles show costs exclusively due to defects.

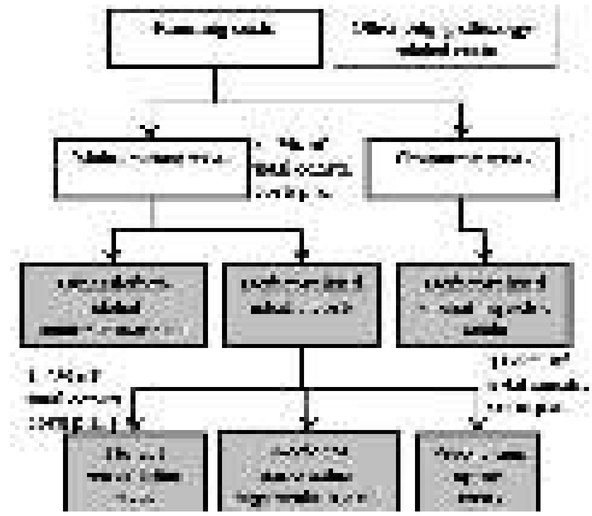

Figure 5 – Building pathology-related additional costs from warranty termination to decommissioning and disposal. Shaded rectangles show costs exclusively due to defects.

2.2.3 DATA ON BUILDING PATHOLOGY RELATED COSTS

Building pathology, through defects, contributes to both quality costs (Figure 4), and running costs (Figure 5). As mentioned above, failure costs, as a part of the quality costs, may be classified in visible or hidden, depending on whether they can be calculated on predominantly objective or subjective criteria.

2.2.3.1 DEFECT RELATED FAILURE COSTS

2.2.3.1.1 VISIBLE COSTS

When defects in a building or in a building element are detected before the warranty termination, corrective interventions such as repair or rework must be carried out, which may involve a number of activities resulting in costs: surveying, inspection and testing; design and detailing of corrective measures and repair or rework proper. Taking into account different sources, it may be said that defect costs through the end of the warranty period, excluding additional maintenance and operation, are in average 3% to 5% of total construction costs [Beukel 1994, Ingvaldsen & Thorbjørn 1994, Mills et al. 2009].

2.2.3.1.2 HIDDEN COSTS

In spite of their inherently subjective nature, it has been estimated that these costs are higher than those of registered failures, and may reach three or four the value of the later [Saukkoriipi & Josephson 2006, Sellés et al. 2008].

2.2.3.2 DEFECT RELATED RUNNING COSTS

Running costs are the sum of maintenance and operating costs. Both may be acted upon by defects, figure 5.

2.2.3.2.1 EXTRA MAINTENANCE COSTS

In the event of defects in a building or in a building element after the warranty termination, causing impaired performance or increased risk, a rehabilitation process may be required involving cost implying activities: surveying, inspection and testing; rehabilitation design and rehabilitation work. In some cases, monitoring and additional maintenance are also in order. As for failure costs, rehabilitation costs may vary widely, as the work may range from local and simple extraordinary maintenance to extensive interventions designed to ensure that the building complies with regulations or specifications. Surveying, inspection and testing costs as those of rehabilitation design are generally taken as percentages of the rehabilitation work itself.

Additional or extraordinary maintenance may be required, either due to the presence of uncorrected defects, or the presence of new products or building elements used in their correction. In both cases additional costs near 2% of the initial value of the building per year are incurred [Ingvaldsen & Thorbjørn 1994].

2.2.3.2.2 EXTRA OPERATING COSTS

Increased operating costs may also be in order, both as a direct or indirect result of the defect. Wrong or out-of-date design options may be the cause of direct increases in operating costs, particularly when they affect a building's energy performance. According to research, the increase in energy consumption can be as high as 70% [Laia et al. 2000].

Percentages similar to that of additional maintenance costs seem to be a conservative estimate of the building direct pathology-related additional operating costs.

An example of indirect operating costs is the loss of occupant workplace productivity. Research has shown that this loss may be as high as 35% due to faulty design [Smith, 1999]. For example, poor interior air quality due to design, construction or maintenance faults is estimated to account for between 60 to 400 billion dollars of lost productivity annually, in the United States alone. [McCurry et al. 2006] However, indirect additional operating costs are difficult to estimate.

2.2.3.3 OTHER BUILDING PATHOLOGY RELATED COSTS

There are no estimations available of the costs on the owner, stakeholders or the sector, referred in 2.2.3 The same applies to the social and environmental costs mentioned therein.

2.2.4 CONCLUSION AND RECOMMENDATION

Average building pathology-related failure costs through the end of the warranty period, i.e., during the construction stage, are roughly 3% to 5% of total construction costs, but may easily reach higher values in particular cases. Hidden costs on the contractor may multiply this percentage by a factor of up to four, even if defect-related liability is disregarded.

Additional running costs related to building pathology may very widely and are therefore difficult to estimate. They may amount to 4% or more of total construction costs per annum.

The above percentages do not include social and environmental costs.

Beukel put together three recommendations for reducing defects, and therefore financial losses [Beukel 1994] which, twenty years later, are still up-to-date:

1. Improvement of the management of all involved processes, by application of modern quality assurance principles. It is believed that practical quality assurance is the only effective way of avoiding building defects. This does not imply that technical knowledge is of less importance. However, quality assurance is an excellent tool for using that knowledge in the right way and in the right place. Quality assurance must not be understood and applied as a "paper tiger", but as a tool in managing processes in an effective and efficient way.
2. Application of risk assessments. This can effectively be done within the context of a quality assurance system. It requires time and money, but it pays off, at least on a macro-economic level. Many defects can be avoided by simple, inexpensive measures. Risk analysis helps in recognizing such measures.
3. Ethics. This term may sound unusual in the context of building defects. However, given that we have so much knowledge and experience in building good, sound buildings, why do we still see defects?

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Figure 6 – Logo of the *Agence Qualité Construction* and of The SINTEF Group

2.3 THE FRENCH, NORWEGIAN AND DANISH EXPERIENCE

(Vasco Peixoto de Freitas, Miguel Vieira and Ana Sofia Guimarães)

2.3.1 INTRODUCTION

In order to accurately access building pathology related costs it is necessary for countries to commit and make an added effort to establish guidelines for data collecting systems, as well as observatories for monitoring the evolution of building defects.

Although useful for a general evaluation, Euroconstruct statistics regarding the overall investment in new building construction, as repair costs, are not enough to fully understand the extent of this issue and apply preventive measures.

In building pathology, one of the most important premises is to "learn from past mistakes", by carefully analyzing each case, determining its causes and elaborating pathology reports, which will allow the acquired knowledge to be available in the future, hopefully contributing to the reduction or elimination of those defects. By doing so, we are able to enhance the quality of construction of our built stock while drastically reducing the considerable amounts spent each year in repair interventions, which can amount to millions of euros.

As a state of the art report in building pathology, it would be of the utmost interest for this document to contain information on this matter regarding each of the countries involved. However, collecting and assessing this kind of data is expensive and time consuming, which explains why most countries have not yet implemented any system whatsoever. Fortunately, a few select nations have foreseen the importance of such knowledge.

2.3.1.1 THE FRENCH EXPERIENCE

In France, the *Agence Qualité Construction* (an organization that assesses and implements quality in construction) in association with the "Fondation Excellence SMA" (a major insurance company operating in the construction field) has developed the SYCODÈS (SYstème de COllecte des DÉSordres), a database comprised of several detailed pathology reports (figure 6).

Since its creation in 1986, the SYCODÉS has been collecting reports originating from claims regarding building pathology, presented to the insurance company. The information given in these reports compiled by expert pathologists provides a vast and important data base of the most common building defects, construction elements affected, underlying causes and the approximate cost of necessary interventions.

2.3.1.2 THE NORWEGIAN EXPERIENCE

Another successful example in this field comes from Norway, where investigations carried out by the Norwegian Building Research Institute (NBRI), have provided crucial data for the analysis of construction quality. Although this information regards the year 2005, it is relevant to demonstrate the importance of these kinds of data collection systems.

The aim of the NBRI was to evaluate the effect of process induced building defects, usually resulting from non-compliance with requirements or specifications, and to establish an electronic archive for those defects.

By collecting data from building defect assignments carried out by the NBRI since 1964 and involving Ph.D students in the process, researchers hoped to attain a clear picture of the Norwegian built environment, using the results to elaborate Codes of Practice and Building Research Design Sheets. These sheets are one of the tools primarily used by designers and architects in Norway up until now.

In 2006, the NBI merged with SINTEF (figure 6), becoming a part of SINTEF's Building Research AS.

2.3.1.3 THE DANISH EXPERIENCE

In Denmark, defect-related are estimated at about 10% of the annual turnover in the construction sector. Since 1986, systems or initiatives applying a carrot-or-stick approach have been implemented in the Danish construction sector to improve the quality of buildings. The initiatives range from mandatory solutions to more or less voluntary benchmarking or insurance-based systems aimed at specific sub-sectors.

Different systems and initiatives have different approaches. Insurance-based mandatory systems for social housing and urban renewal introduced around 1990 showed remarkable results expressed by the reduction in the volume of defects, but when more or less voluntary systems were introduced for single-family houses a similar success was not seen. This is explained by too little information about the cost-benefit and the ease of avoiding taking out an insurance policy. Mandatory systems seem to be preferable, depending on the target group and the institutional settings.

Since 2009, authorities no longer examine the project documentation when issuing building permissions for smaller buildings. Together with the gradually more performance-based Building Regulations this is criticized for favouring large contractors. The amount of requirements that companies must fulfil should be put against the risk of excluding small contractors, without knowing whether smaller contractors construct houses with lower quality.

2.3.2 DEFECT DISTRIBUTION

The information collected in France and Norway allowed for an overall view of the manifestation of building defects, regarding its most common causes, construction elements affected and accountable intervenients in the building process.

2.3.2.1 BUILDING ELEMENTS AFFECTED

In Norway, construction elements located in the building envelope account for almost two thirds of all observed defects (figure 7). Figures 8 and 9 shows the building defects according to type of external wall and to type of roof, between 1993 and 2002, respectively. In France, the building envelop elements such as façades, roofs and terraces, account for approximately 35% of reported defects between 1995 and 2009 (Figure 10)

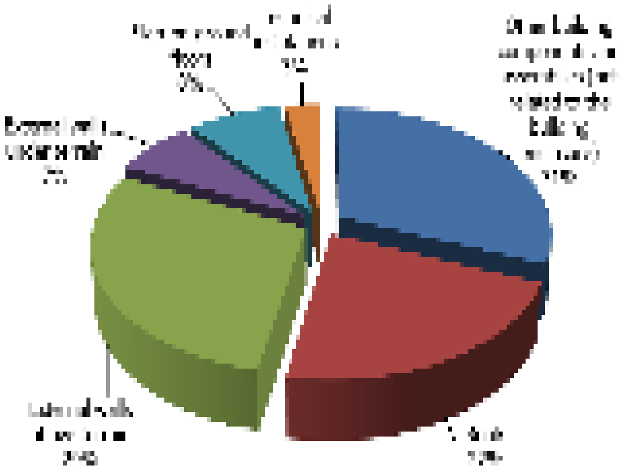

Figure 7 – Distribution of process-induced building defects between 1993 and 2002, according to building element – NBRI.

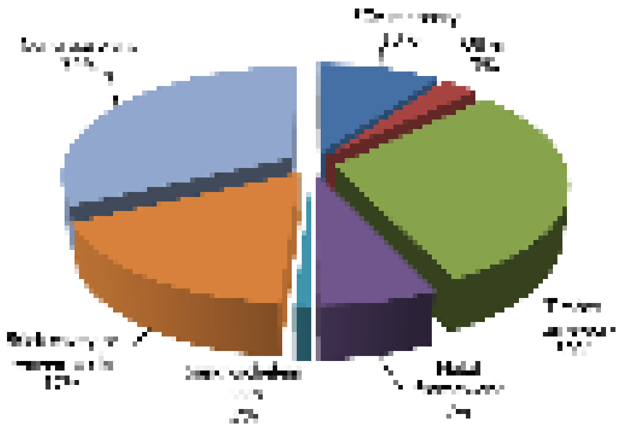

Figure 8 – Distribution of process-induced building defects between 1993 and 2002, according to type of external wall – NBRI.

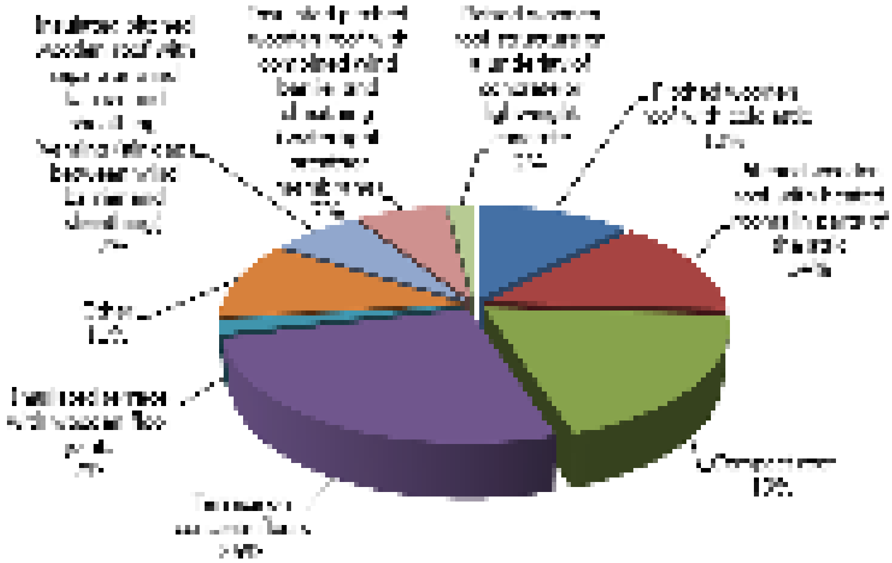

Figure 9 – Distribution of process-induced building defects between 1993 and 2002, according to the type of roof – NBRI

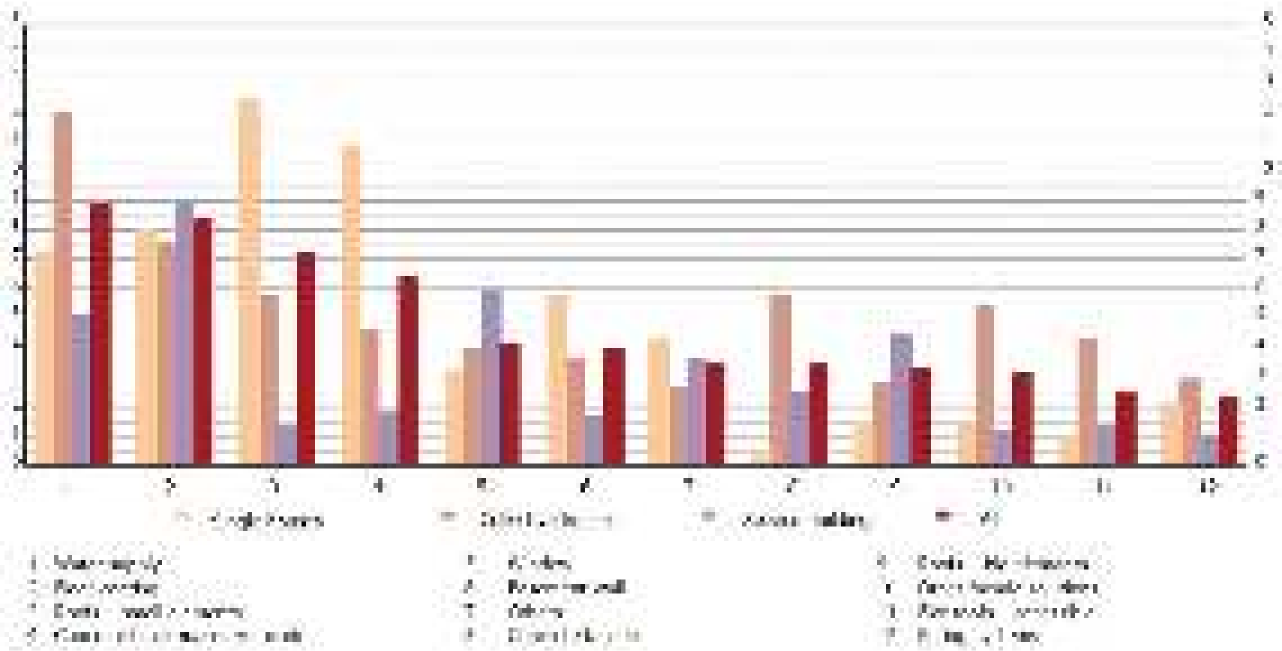

Figure 10 – Hierarchy (%) of the nature of building defects, considering several types of buildings - Sycodès.

2.3.2.2 UNDERLYING CAUSES

It is clear that the most common cause of building defects is water and all its inherent problems: defective insulation, water leakage, moisture, condensations, etc. Despite the technological and technical advances in construction and materials, preventing water-related defects still poses a great challenge for engineers and designers alike. Carefully planning ahead in the design stage, opting for adequate materials and solutions and providing thoroughly detailed projects to contractors may help prevent many of these defects. Both in Norway (Figure 11) and France (Figure 12), water/moisture-related defects are a common denominator. Another very important parameter provided by the Sycodès, is the type of observed building defect according to all the variables and intervenients in the building process (Figure 13). As expected, almost 80% of all defects result from mistakes made at the time of execution, whereas about 10% are the result of design flaws.

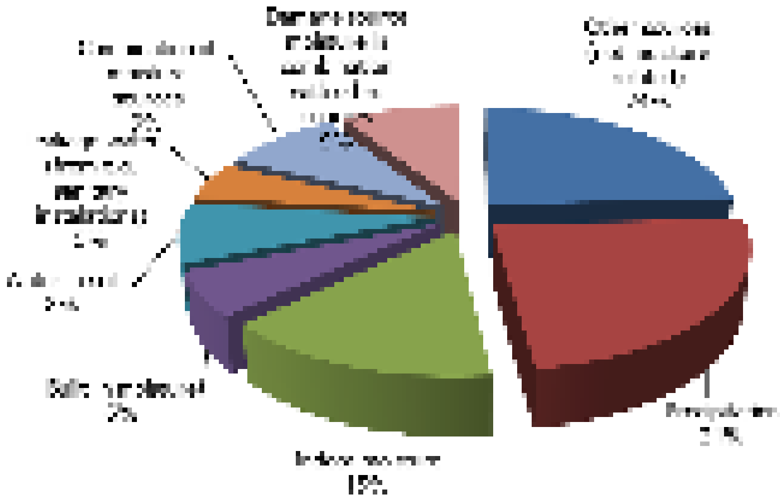

Figure 11 – Distribution of process-induced building defects according water-moisture related defects between 1993 and 2002 – NBRI.

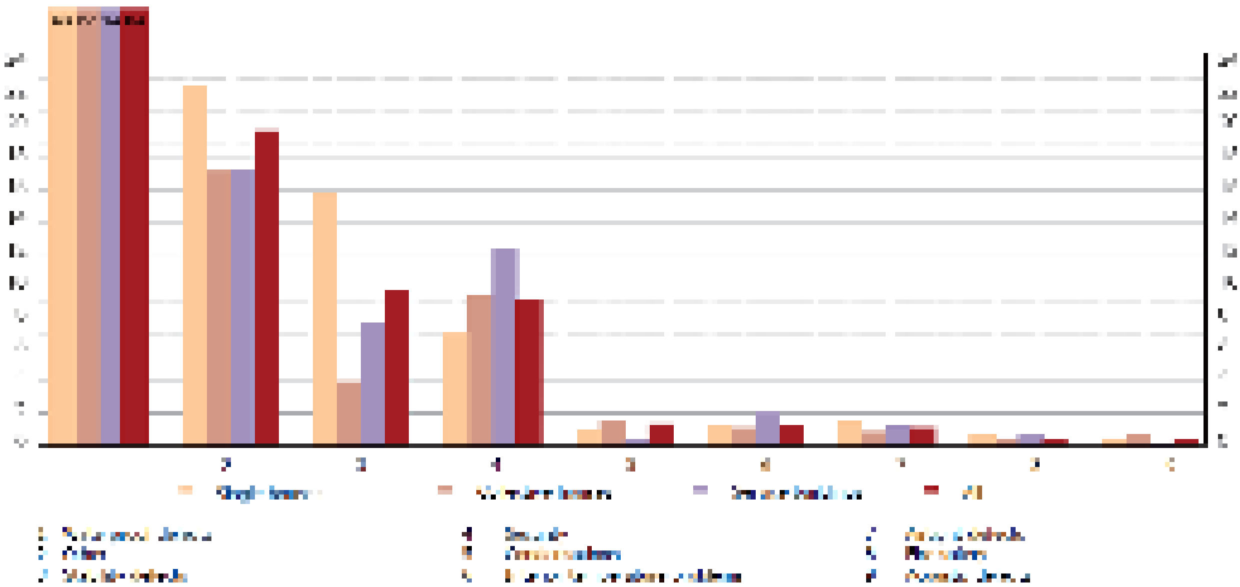

Figure 12 – Distribution (%) of building defects between 1995 and 2009, according to causes – Sycodès.

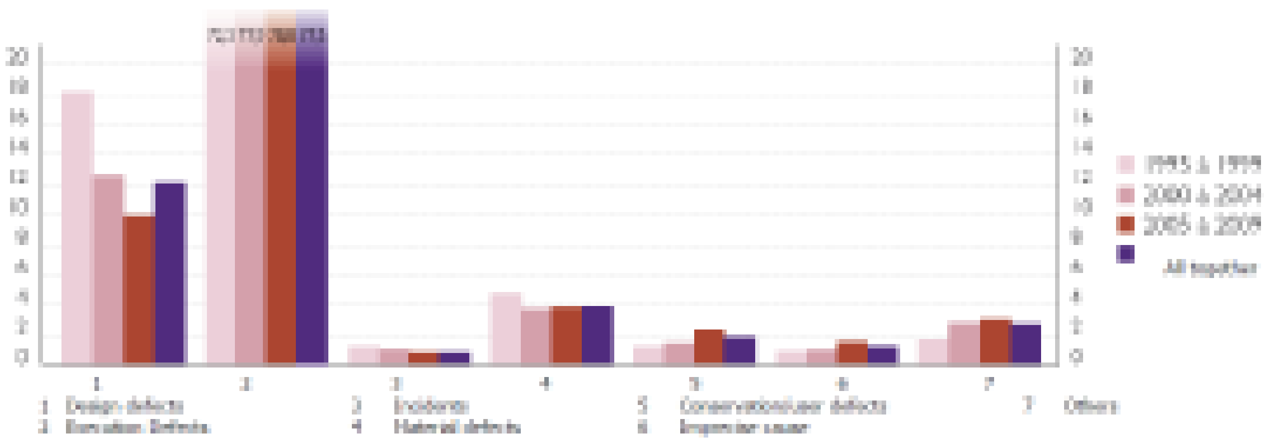

Figure 13 – Distribution (%) of building defects, according to the intervenients in building process – Sycodès.

2.3.3 DEFECT-RELATED COSTS

As regards the annual costs related with building pathology, the most common numbers are provided by Euroconstruct and focus on the ratio between investment in new construction and early costs of repair and retrofitting. According our knowledge, only the French system is capable of providing a further analysis and evaluation of relevant parameters. In its reports, the Sycodès is able to provide the average cost of repairs, according to the nature of the problem, building element affected, and type.

As expected, the most expensive repairs are those related with foundations and structures, followed by interventions on interior coatings/coverings (Table 1).

The available data from the Norwegian study only pointed out an overall picture: at the time (2005), it was estimated that the annual investment in the construction industry was about 130 billion NOK (approx. 16 523 000 000 €), whereas the costs of repairing damages and defects accounted for about 10% that value, roughly 13 bilion NOK (approx. 1 652 300 000 €). This proportion of 10% is to this day, an accepted number among several European countries. These numbers, although interesting, are ultimately insufficient for an understanding of the phenomenon of building defects in each country, and as such, for the implementation of effective measures to prevent future occurrences. This is where the importance of building pathology observatories and monitoring programs becomes clear.

Figure 14 corroborates the fact that foundations constitute a crucial element when it comes to building pathology costs, also providing the cost hierarchy for other construction elements.

By carefully analyzing and cross checking the different information resulting from the Sycodès, it is possible for researchers to determine the best course of action and focus their efforts in the right direction.

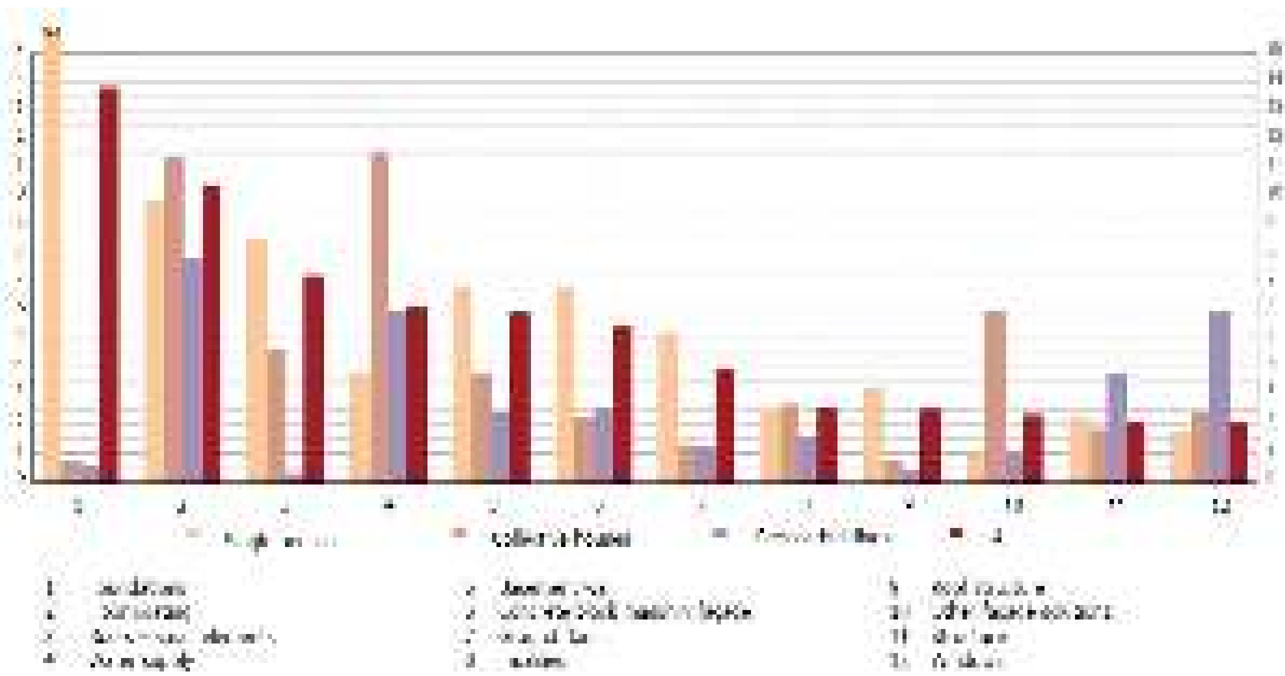

Figure 14 – Hierarchy (%) of the cost of building defects, according to building element– Sycodès.

Table 1 – Average repair cost according to nature of defect

Nature of Defect	Period			
	1995-1999	**2000-2004**	**2005-2009**	**Average**
Exterior of Building	7 110	5 450	5 590	5 810
Foundations	12 610	12 440	12 630	12 560
Structures	8 940	9 010	7 110	8 060
Roof	4 810	4 680	4 430	4 580
Terrace	5 350	5 630	4 280	4 890
Façade	5 090	4 320	4 160	4 380
Windows	3 810	3 690	3 630	3 700
Internal Coatings	7 010	5 810	5 860	6 050
HVAC	4 660	4 320	4 140	4 320
Other Equip.	3 780	3 800	3 660	3 720
Average	**6 280**	**5 730**	**5 360**	**5650**

Table 2 – Average repair cost according to the intervenients in the building

Type of Defect	1995-1999	2000-2004	2005-2009	Average
Design	11 680	11 780	11 830	11 770
Execution	5 050	4 770	4 540	4 700
On-site	4 720	4 840	6 670	5 670
Material	5 390	5 410	6 070	5 720
Misuse	5 090	5 940	3 980	4 610
Imputable anomaly	5 410	5 530	5 310	5 380
Other	7 420	6 190	4 970	5 680
Average	**6280**	**5 730**	**5 360**	**5 650**

Although "execution defects" are the most common. The cost of repair is onavarage about 2,5 times less expensive than "design defects". Also, imputable anomalies (i.e. defects which can be attributed to erroneous conduct by one of the intervenients in the building process) lead to more expensive interventions than those caused by "execution defects" (Table 2).

2.3.4 CONCLUSION

It is very important to collate the reports made by experts in the different countries in order to understand the most common building defects and their causes and estimate the annual repair costs.

This was not done in many contries probably because the mandatory insurance systems are not implemented.

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CHAPTER 3

METHODOLOGY OF INVESTIGATION

3.1 FROM SINGULAR, ACCIDENTAL BUILDING PROBLEMS TO EARLY DEFECTS OF A CONGENITAL NATURE

(Joan Lluís Zamora i Mestre)

Figure 15 – View photo of a set of newly constructed residential buildings in urban peripheries

3.1.1 INTRODUCTION

Buildings constructed in the second half of the twentieth century will most likely be characterized by the fact that they were mass produced as just any other consumer good These recent buildings have been produced by specialized companies, which have put them on the market for sale or rent. However, at the time of their production, it was not known who would how they would be lived in (Figure 15).

The experts, who defined the building programme and specified the building techniques, as well as the workers and products involved in the construction, originate from places which are physically and culturally distant from the area in which the building is located. As a result of these differences, the technical discipline of building pathology is now in another context that is notably different from the traditional scenario.

3.1.2 SINGULAR AND ACCIDENTAL PROBLEMS

For centuries, building pathology has been a discipline aimed at studying problems those accidently affect individual buildings of a certain age, leading to obvious damage that is a cause of social alarm. The work of experts is needed to assess this damage and even propose interventions for repairs.

When carrying out this expert task, there is usually a lack of prior information on the building, given that with the passing of time, contact with agents who worked on the building is lost and the original written information is dispersed.

In addition, building pathologists are always handicapped by the fact that they have to adequately interpret the construction techniques that have been used successively in the damaged building, due to its constant evolution and restructuring. Only important monuments have records of all the work that has been carried out.
In this context, the work of the building pathologist is markedly archaeological for the following reasons: the cause of the defect is the passage of time; the reconstruction of information is always partial and limited due to the availability of documents; and the final conclusions are often attained in collaboration with other experts. The social responsibility of the building pathologist generally only comes into play when the damage is so great that the building is on the fine line between repairable and ruin. In this case, experts have to decide whether the affected element is worth repairing or should simply be replaced.

3.1.3 GENERIC DEFECTS OF A CONGENITAL NATURE

In contrast, mass-produced modern buildings (such as industrial premises, schools, offices and dwellings) often have construction defects that appear early in the first few years into the building's life. In this context, the building pathologist's work is clearly different from that carried out in the traditional scenario described above. In this case:

The owners of the defective building are its users who feel personally affected. As a result, they express their indignation as citizens and consumers. This condition of being both citizen and consumer means that the government guarantees the users' rights through the relevant legislation. This guarantee in response to the adversity that a defect represents is essentially financial, through a system of compulsory insurance policies.

The rights of a building's owners are guaranteed for a limited period of time, whose length depends on the defect (if it is in the cladding, in the functional elements that provide services or in the supporting elements). Therefore, the building pathologist must act at a very early stage, spurred on by the guarantee's expiration terms.

The reported defect is usually of low severity, but appears quickly and progressively with use and the passing of time. The problem that initially causes alarm and leads a citizen to make a claim is not always based on a technically sound argument. However, the complaint reflects an imbalance between the consumer's expectations and the real behavior of the building.
The building pathologist has fast, easy access to large amounts of technical information, as neither the documents nor the agents who worked on the building have yet been lost with the passing of time. The availability of information means that research into the cause of the defect can begin using the documents. This work method is based on the industrial quality control criterion of traceability, which enables us to trace any process back uninterruptedly until we find the link in the chain in which the error or omission that led to the defect occurred. The criterion that enables us to determine whether each and every one of the activities that took place in the course of the building work was correct or not is based on the prior existence of standard public protocols or regulations, which establish the specific requirements that apply, as well as acceptable and unacceptable.

In this context, the authority of the building pathologist is called upon to specify various interrelated aspects:

a. He/she must define whether the reported defects are "acceptable" or whether they can really be classified as damages. In this case, the different levels of severity are specified;

b. He/she has to establish rigorously and clearly the scientific and technical causal connection between these damages and the defects that provoked them;

c. He/she has to determine whether the cause of the damage lies in a defect of the building or incorrect use by the citizen-consumer;

d. He/she has to attribute responsibility for the damage to specific agents who participated in the construction of the building, in order to claim compensation from the irrefutably or to ask them to do the repair;

e. He/she has to assess the direct (repair work) and indirect (safety measures, protection of the rest of the building, rehousing, management, etc.) costs of the work required to repair the damage.

More recently, it has become common for users to attribute responsibility to the agents involved in the construction of a building. As a result, this kind of conflicts has been institutionalized either through the creation of expert technical services by the after-sales departments of construction and insurance companies, or the establishment of arbitration councils that are also comprised of building pathologists.

The creation of such services, departments or councils with the involvement of numerous building pathologists, limits, as far as possible, the time and money that may be spent as a result of consumer claims. Therefore, a new characteristic is the confrontation and debate that usually arises between different pathologists, who may defend conflicting technical contents, but always have the financial consequences of the confrontation in mind.

3.1.4 AN UPDATE EXPERT METHOD

In recently constructed, mass-produced buildings, the reported defects are usually not severe but are widespread. In this case, a preliminary report on the defects is of key importance as it becomes a systematic descriptive record, which is markedly different from the subsequent interpretation of the results before the diagnosis. This record could be:

— Synchronous: all of the defects are recorded in a short period of time, with their most relevant descriptive parameters (photographs, dimensions and description) as well as their position (x,y,z) in the geometry of the building (Figures 16, 17 and 18);

— Diachronic: all the defects must be recorded at different stages to assess their evolution over time. They may get worse (increase in the size or severity of the problem) or stay the same. In some cases, a diachronic record should be used to assess whether or not a repair has been successful (Figures 19 and 20).

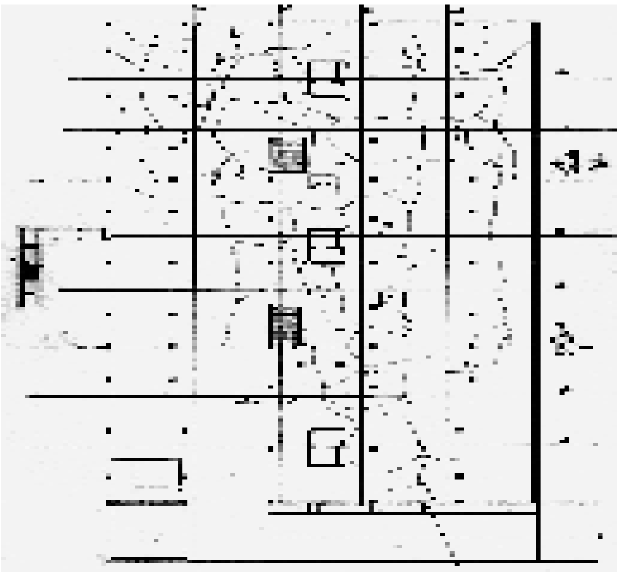
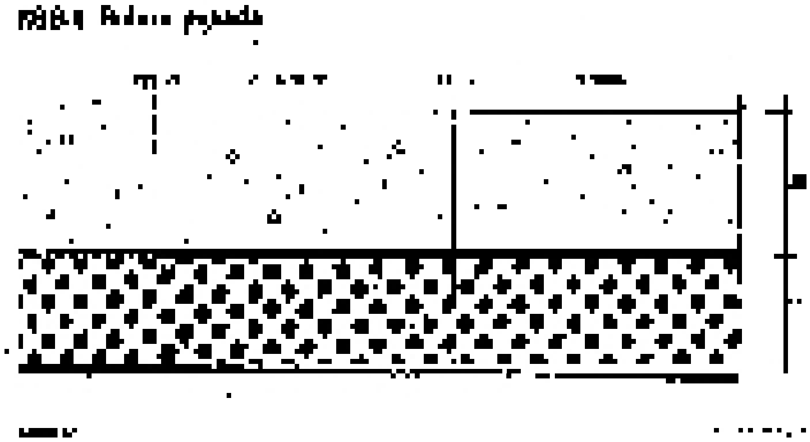


Figure 16 – Planimetry of a large crack in the floor of underground parking of vehicles in an apartment building

Figure 17 – General view photo of underground parking of vehicles in an apartment building



EFH-2

Sand, with maximum grain size 0.5 cm forming a layer 15 cm thick, spread over ground mechanically compacted to achieve a value of 90% of Standard Proctor. It will end the process before making up the sand compacted in two layers.

RSL-9

Polyethylene insulation sheet.

EFH-7

Concrete characteristic strength 250 kg/cm2 in a layer 20 cm thick, spread over the insulation sheet. The surface will be completed by past master. Curing is effected by irrigation but not producing faded.

Figure 18 – Specification image from official technical regulations

Figure 19 – Planimetry of the points of infiltration of rainwater on the roof of an apartment building

Figure 20 – Thermographic and visible photography points of infiltration of rainwater under the roof of an apartment building

Before the cause of the recorded defects is assessed scientifically and technically, and likely models of deterioration are determined, we must first analyze the records statistically, to differentiate whether each defect is a one-off, and therefore due to an accident, or widespread. If it is widespread, it is probably due to defects that occurred in the mass production processes.

When this information has been gathered, the building pathologist can specify the various interrelated aspects mentioned above:

A.

The damage has to be described on a scale of severity, to facilitate various essential decisions that must be made in the process of attributing responsibilities:

— Does the defect need to be repaired or is it enough to compensate for the reduction in value?

— Before repairs are made, does the entire building need to be vacated or can most of the building use continue as normal, except for the part affected by the defective construction element?

— Should the fault be repaired immediately as an urgent procedure or can an ordinary procedure be used?

Currently, there are no clear or recognized scales of severity for building pathology. Therefore, building pathologists have to check each defect for compliance with the basic requirements established in construction standards, such as those drawn up by the EU. With the experience acquired over the years, building pathologists achieve a balance between caution and alarmism.

However, all arguments must be based on the preliminary records report (Figures 21 and 22).

B.

The scientific and technical relation between the hypothetical defects and the observed damage must be deduced. To achieve this, experts must resort to arguments of authority. There is much appreciation for the efforts made by institutions and research groups to build online databases that can be accessed through the internet. These databases carefully describe defective processes that may arise in buildings and enable pathologists to deduce whether the specific case that they are working on is of the same type as that described in the technical literature (Figures 23, 24 and 25). It is regrettable that in this aspect the insurance companies, the entities that probably have the most statistical information on this subject, are so zealous with their data and do not usually publish it, so as to provide better protection for their policyholders.

C.

We have to differentiate whether the cause of the abnormal damage lies in a congenital defect in the construction of a building or inappropriate use or handling of the good by the citizen-consumer. In the case of an early generic defect, this differentiation is of great importance.

The processes of manufacturing and installing construction products have evolved extremely rapidly in recent years, unfortunately, at a greater speed than the professional training of workers and technicians of the companies that use those materials. This imbalance is the cause of many defects in current construction.

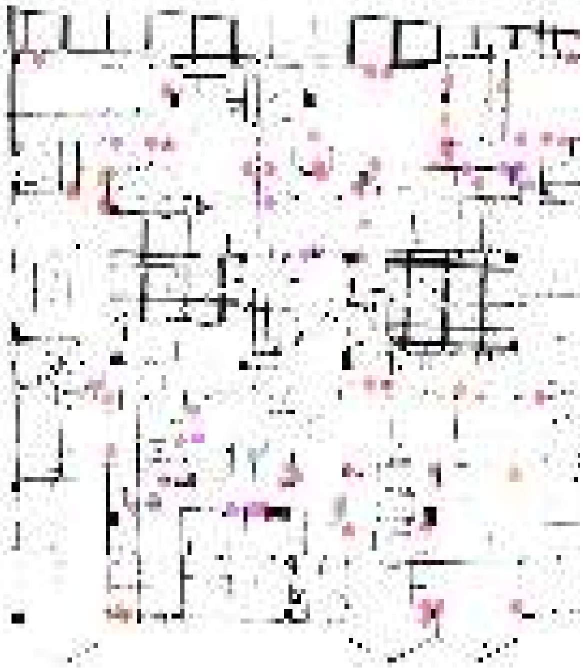


Figure 21 – Planimetry of the points of infiltration of rainwater on the roof of an apartment building

Figure 22 – view detail photo of cracking in the walls of masonry of ceramic pieces in an apartment building

In addition, various adverse circumstances may arise on building sites, some of which have not been studied widely to this date:

1. Some of the interfaces between different, highly developed construction technologies are not specifically considered in the design.
2. During the building work, undocumented changes may be made to the design, which are accepted by the participating agents due to circumstances limiting the available time or money.
3. Situations of congestion may occur (for example, an increase in the number of workers on site at the same time) or there may be pressure to work faster (for example, the timelines are reduced). This leads to the appearance of defects.
4. Signs of technical information loss in the process of transmission from the designer to the worker.

The building pathologist is not always necessarily an expert in processes of implementing construction techniques. Therefore, he/she must compensate for this lack of knowledge by carefully reading the records of the building's construction process, which in some cases have become real "black boxes".

Workers and companies may not have received an up to date training, which may have an impact on the citizens-consumers who use a building. As a result, users may lack in-depth knowledge of the building's technical characteristics. Therefore, it is essential to carefully read the manual on the use and maintenance of the building, and compare this with the actual way that different people use it.

However, the experience of many pathology experts establishes the existence of defects in buildings that do not necessarily emerge as damages, when this aspect of the building is not used to a sufficient degree.

D.

It is essential to establish unequivocally, on social demand, who is to blame or responsible for the defect that has caused the damage. This is now a difficult task as an increasing number of agents are involved in building work. They are usually not on site continuously and they have highly varied partial responsibilities.

The daily experience of a building pathologist shows that in current construction processes, the rigorousness of quality control and preventive measures is high enough to prevent one defect from being great enough to cause damage. When a problem does arise, it is generally the result of various consecutive and associated errors. Therefore, it is very difficult to attribute the defect to one agent. The tendency in such cases is to implicate the professional who is immediately above the level at which the error occurred, with the argument that the failure was due to a lack of supervision. This implication usually leads to financial compensation, but does not often result in preventive measures.

E

As a conclusion to their expert reports, building pathologists have to estimate a value for the repair costs. This value must always be provided prior to any repair plan. This is a technically difficult task for building pathologists, as this first evaluation may be highly imprecise, given that repair works are always uncertain and inefficient. In addition, there are no are large enough or verified databases in this field. One solution that is accepted in some cases is to establish cost ranges (with expected maximum and minimum values). However, as the reason for all of this work is usually a claim or legal process, the judge or insurer must establish specific funds to ensure the repair can be carried out in the future. It is up to the building pathologist to decide on this amount.

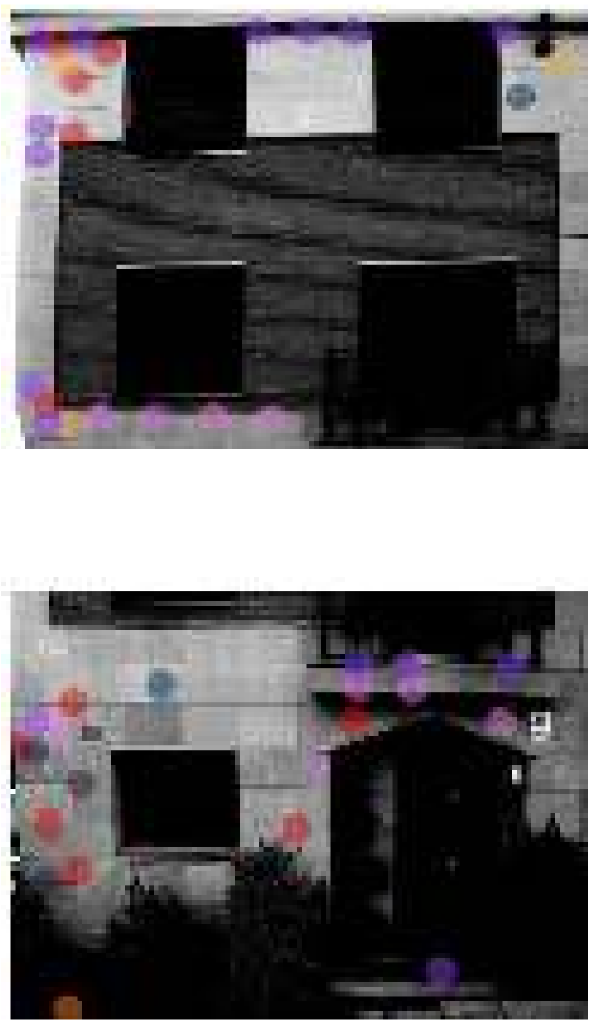


Figure 23 – Planimetry based on photographs to facilitate identification, census and classification of anomalies detected in the natural stone façade placated by a group of single houses

Figure 24 – Proposal for classification of the anomalies detected in the natural stone façade placated by a group of single houses

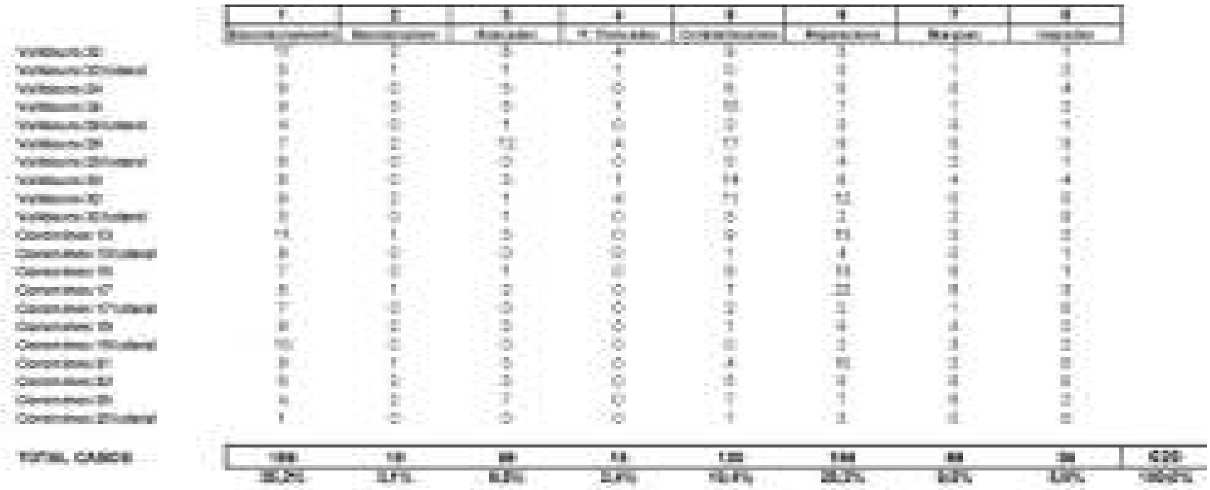


Figure 25 – Statistical processing of the anomalies previously detected and classified in the census of placated natural stone facade by a group of single houses

3.1.5 CONCLUSIONS

The professional work of many building pathologists is taking a new direction due to conflicts related to early defects, caused by generic congenital flaws. The new buildings are considered by current societies as goods that should be perfect and impeccable from day one, although it is recognized that they quickly become outdated in technical terms, like any other good. This has led to a quantitative change in the professional activity of building pathologists who now tend to work in the early phases of a building's life, almost in apparent continuity with the quality control processes of the construction work.

This change in the focus of building pathology activity should be reflected in the objectives and results of research and innovation in this field in the coming years, to take advantage of the experience gained in this discipline and to incorporate methods and knowledge from the consumer goods industry.

simplicity. It is also convenient to use small battery powered hand-saws and easy-to-use hammer drills for the purpose of getting a clear view of hidden elements or allowing for the use of binoculars or endoscopes.

3.2 SOME CONSIDERATIONS ABOUT OBSERVATION METHODS, MEASUREMENTS AND TESTS FOR TECHNICAL INSPECTION OF BUILDINGS

(César Díaz-Gómez)

There is a growing number of cities all around the world that regulate the technical inspection of buildings with the aim of increasing their levels of safety and to encourage their preventive maintenance. This is established through statutes which establish the resources to be used for the inspection process. It can vary from a strict interpretation of the damages based on what can be percieved directly from a visual inspection, to the possibility of realizing a set number of holes or drills in order to see hidden areas, or even, in some cases, to carry out some simple and economic tests to establish a more accurate diagnosis.

These inspections involve hundreds of thousands of buildings and they often have to be realized within a limited period of time. This is the reason why there is a growing need to revise and to improve the variety of existing resources for the survey on site with the aim of adapting their use and characteristics to the objectives set out in the statutory technical inspections. We refer particularly to those resources that are used the most during the diagnosis period.

3.2.1 RESOURCES FOR VISUALIZING HIDDEN AREAS

There are often hidden areas in buildings, above suspended ceilings, behind partitions or tiles which impede the observation of the condition of the construction elements to be inspected. Other times, it is necessary to inspect parts of those elements that are built into walls like, for example, the ends of timber beams which are susceptible to rot. Making openings, generally by using a hammer and chisel, and extracting an amount of material just sufficient to be able to see the desired area, has become the most common type of intervention, despite its evident

3.2.2 RESOURCES FOR VERIFYING ADHERENCE

It is usually recommend in all inspections to check the adherence of continuous render finishes or of ceramic tiles to a façade, with the aim of detecting the risk of possible detachment. This is normally done by tapping on the surface with a hammer that can produce a revealing hollow sound at the areas which are not properly adhered. The correct size of the hammer will vary depending on the thickness and hardness of the covering material. This technique is generally enough for the aim of inspection, although you can get more information regarding the adherence, between the render and its support or between the mortar and the ceramic tiles, from standard pull-off tests which are generally quite easy to perform. The main problem for this part of the inspection is not carrying out the tests themselves, but gaining access to the most exposed areas susceptible of showing reduced adherence, often at the very top of the façades (the most exposed areas to thermal changes and wind-borne moisture). Obviously, any innovation to assist access to difficult areas or any other part of the external finishings would representa huge advance of unquestionable value for the aim of such inspections.

3.2.3 RESOURCES FOR MEASURING THE SIZE OF FISSURES AND CRACKS

The measurement of the width of fissures and cracks allows us to determine if they exceed the limits set in regulations and instructions for cracks, or the magnitude of differential movement between two elements or two parts of the same element. Different types of tools exist for those measurements, from transparent plastic rules with different reference widths, to a magnifying glass with a scale and torch incorporated, that can measure down to a tenth of a millimetre with great clarity. It is not normal to follow the development of those damages during the inspection process because that would generally require a prolonged investigation, which is not the original aim of the required inspection. There are many resources available when cracking follow-up is required, allowing for a choice between qualitative methods - which only register if there is movement or not - such as the plaster or glass tell-tale, and quantitative methods - capable of measuring differences in the width of cracks - such as callipers, dilatometers and expanding gauges, among others.

3.2.4 RESOURCES FOR MEASURING SAGGING OF FLOORS

The extent of sagging of floors - especially those with timber beams and joists - represents a value that can be associated with the degree of its strength in reserve. There are values relating deflection and span, which set the acceptable limits in normal load conditions. To acquire such data, it is common to simply use a string pulled tight between each end of the beam or joist, and a rigid measuring tape to measure the greatest vertical distance between the string and the lower plane of the timber element. Even though this operation requires three people, it is difficult to articulate more agile ways of doing it, unless one designs a device capable of projecting a line of light that follows the string between both ends of the sagging element. Anyhow, there are no appropriate devices available yet to realize such an operation.

3.2.5 RESOURCES TO QUANTIFY THE MISALIGNEMENT AND IRREGULARITY OF FAÇADES

The resources used to measure the misalignment and irregularity of façades, are similar to those used to measure sagging as previously mentioned. The only difference is that in the case of façades the string is used as a plumb line with the addition of a weight at the bottom, allowing the use of a rigid measuring tape to get the distance between the wall and the string. The relationship between this measurement and the façade height is generally a reference to be compared with established limits.

3.2.6 RESOURCES TO CHECK THE CONDITION OF STRUCTURAL TIMBER ELEMENTS

It is quite common to complement the visual inspection of timber elements, with the additional operation of drilling a hole in the areas with higher risk of incurring biological attacks (fungus, wood-damaging insects, etc.), in order to check their strength. Occasionally, symptoms of those attacks are apparent at wood's surface, in which case puncturing to check its strength is highly recommended. The more common tools used to carry this out are an awl, a screwdriver or even small battery powered drills. However, there are no specific tools designed for these operations, which would provide more accurate information on the reduction in strength of the timber under inspection.

3.2.7 RESOURCES TO CHECK THE CONDITION OF STRUCTURAL CONCRETE ELEMENTS

For this type of inspection, the diagnosis is usually based on detecting cracks in the different structural elements of the building and identifying where those findings coincide with the parts under the most stress. It is also common practice during inspections to check the extent of sagging in the floor slab when sets of cracks resulting from deformation are observed, as well as checking for signs of steel reinforcement corrosion, visible as rust stains or cracks coinciding with the reinforcement's position, which can be located, in case of doubt, with a pachometer. Information about the characteristics of the cement used during the manufacturing of prefabricated elements, and the degree of concrete carbonation, can be attained during the process of inspection, by carrying out additional simple tests that can be realized in-situ, such as oxine and phenolphthalein tests. The extraction of standardized test cores of small diameter can be used to get an idea of the strength of the concrete in the beams. This normally exceeds the requirements in the strict terms of the inspections but it is noted as a useful and affordable resource that helps in obtaining data about the characteristics of the materials.

3.2.8 FINAL CONSIDERATIONS

Without trying to be comprehensive regarding the resources that can be applied in the process of inspection and diagnosis of buildings, our goal was to highlight whatever is specific about the process of diagnosis as foreseen in the statutes for methodical inspections of the building stock, refer that to the methods and tools of everyday use, and point out some courses of action aimed at obtaining more specific information about the most common materials and elements. Efficiency in achieving the objectives foreseen, while assuring that the inspections can be realized at a reasonable cost to both users and owners of the building, requires improvement, not only in the degree of preparation of the inspectors, but also in optimizing the material resources available to proceed with the diagnosis.

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3.3 DIAGNOSTIC METHODOLOGICAL APPROACH: INNOVATIVE ASPECTS FOR MASONRY STRUCTURES

(Fabio Fatiguso and Albina Scioti)

3.3.1 RESOURCES FOR VISUALIZING HIDDEN AREAS

Nowadays there is a widely shared and increasing attention towards the built heritage, mainly comprised of historic buildings, but also including more modern structures that are often characterized by severe decay. In fact, a new concept of town development, primarily based on quality of life, has recently required the refurbishment, retrofitting and preservation of buildings and urban areas, through specific intervention criteria and methodologies, especially whenever historical and architectural values are involved.

Within this scenario, knowledge is a prominent issue. Specifically, knowledge - i.e. the qualification of historic features, materials and construction techniques, structural and functional modifications, and building and elements state of conservation - is the necessary preliminary phase for the assessment of residual performance and, thus, the definition of appropriate refurbishment/maintenance works.

It should be noticed that the variety of available investigation approaches and methods, requires the knowledge process to be carefully organized, in order to optimize time and techniques, as well as to continuously verify the consistency of the qualification needs with the building's history, technical/ technological features, and state of conservation.

In fact, the imprecise application of methods and techniques seldom leads to a satisfying outcome, because data might be meaningless and/or not correlated, allowing for a comprehensive analysis of the design development.

Nevertheless, the truth remains that despite the diffuse awareness of basic alteration mechanisms and the wide availability of diagnostic tools, the definition of practices and procedures for diagnostic investigation, according to a multidisciplinary approach, still poses a challenge, in what regards supporting and guiding professionals and operators in the field of building refurbishment.

The lack of a systemic vision generally implies the development of a highly specialized approach, which might prevent the correlation of several investigated aspects. Besides, there are limited normative standards about technical procedures to evaluate the condition of existing buildings. As a result, it is reasonable to carry out all the possible tests in order to achieve a complete performance assessment. Finally, since there are limited recommendations on testing methods, application procedures and data interpretation routines, the investigation process to assess the quality of materials and structures is mainly based on intuition, experience and expertise.

From the analysis of the methodologies for an investigation programme, the present contribution points out the importance of defining a knowledge framework, as a decision-making support tool, where choices and expected results are consistent.

Namely, it is possible to review and update a well established structure of a diagnosis and intervention process, with reference to the following macro tasks: Basic Knowledge, Data Management, Preliminary Analysis and Pre-Diagnosis, Further Knowledge, Diagnosis, Project, Intervention, Intervention Assessment, and Maintenance. Each macro task will be further divided into sub-tasks in order to point out the links of the decision-making process with the available databases (atlases of construction typologies, materials, pathologies, investigation methods and techniques) and technical legislation codes.

The complexity of structural systems and characteristics within the built heritage, as well as the variety of involved disciplines, requires the definition of diagnostic tools from two points of view: on the one hand, the systematisation of up-to-date knowledge; on the other hand, the structuring of the diagnostic testing programme, in terms of procedures, tools, application and interpretation routines.

3.3.2 THE DIAGNOSTIC PROCESS

3.3.2.1 METHODOLOGICAL APPROACHES

The term "diagnostics" stands for a system of tools, methodologies and procedures that guide and control the diagnostic investigation, from the detection of anomalies/pathologies/ decay conditions, to be analysed as symptomatic evidence, up to the diagnosis and defect assessment. Therefore, the main goal is to reduce as much as possible the uncertain interpretation of symptoms, through an approach comprised of different specializations.

Over the last years, the awareness of basic alteration mechanisms and the availability of diagnostic tools have been widely developed. However, managing large amounts of data, coming from the extensive application of destructive and non destructive techniques, is still very challenging. The reason might be the shortage of guidelines/recommendations for practices and procedures, as well as the poor understanding of advantages and disadvantages of each investigation method.

The scientific community has focused on procedure models, data bases, pathology observatories, atlases of structured knowledge, expert systems, and algorithms to analyze the complexity of decay and pathology phenomena.

As a result, the critical issues are mainly basic knowledge, data management, diagnosis and diagnostic support tools.

3.3.2.2 PROCESS PHASES

Previous studies and researches have defined the general diagnostic process framework (W86 CIB Report, 1993), whose fundamental phases are:

- ***Preliminary knowledge*** of the technical features and visible anomalies of building components;
- ***Pre-diagnosis****,* where the initial survey is elaborated, a possible diagnosis is formulated and diagnostics phases are scheduled;
- ***Diagnosis***, where phenomenological models and experimental tests are developed in order to validate the pre-diagnosis hypotheses.

The ***preliminary knowledge*** concerns the survey of construction techniques, visible anomalies and decay phenomena, and surrounding environmental conditions. Data is collected without any critical interpretation, because a pre-diagnosis hypothesis at this stage could lead to ruling out information that might not seem relevant in the light of a partial analysis.

Specifically, as far as historical buildings are concerned, preliminary knowledge requires two main sub-phases: (1) preliminary survey of geometry, materials and construction techniques; photographic documentation; mapping of pathology and surface decay patterns; detection of indoor comfort parameters; (2) historical research in archives, libraries, heritage conservation institutions, land registries, and direct testimonials.

All the information should be organized for the following pre-diagnosis. Although the preliminary knowledge should be regulated by normalized standards, they are still missing to this day. However, some authors have proposed some methodologies for survey data collection and elaboration [Fiorani D., 2004; Docci M., Maestri D., 2009].

The ***pre-diagnosis*** is the phase where the information from preliminary knowledge is elaborated, in order to formulate the early diagnosis hypotheses and schedule the onsite investigation to validate them. The onsite investigation programme aims to select the destructive and non-destructive techniques, in terms of experimental set-up (number of tests, measurement points and/or areas,) and their possible correlations and complementarities. Several authors [Croce S., 1986; Croce S., Boltri P., Turchini G., 1992; Croce S., Lucchini A., Turchini G., 1992; Croce S., 1994], with specific reference to recent buildings, point out that the list of early diagnostic hypotheses can be progressively narrowed down by carrying out: first, the statistical elaboration of preliminary knowledge data; then, the analysis, also by means of theoretical models; finally, the interpretation of results from the onsite investigation, which might help list the alternatives according to a priority index.

Several methods and tools are available for diagnostic development, including the fault tree, diagnostic tree, and phenomenological models. They are all developed in order to make the diagnosis as impartial and straightforward as possible.

The *fault tree*, first developed in the industry sector, is a deductive failure analysis tool. It attempts to model and visualize failure processes in a building system/component, by means of a diagram, which displays the logical relations between an undesired event – i.e. the failure - and possible causes leading to that – i.e. the error. Specifically, for failure detection, the method analyses and orders the chain of critical events that might lead to that specific failure, depending on the functioning conditions.

The *diagnostic tree* is a procedural guide for the development of a diagnostic investigation. It supports in selecting specific branches of the fault tree, by providing a sequence of questions that might help the decision in several ways.

The *model-based analyses* enable the representation of pathological phenomena, from a quantitative and qualitative point of view. Such an engineering approach aims at studying a phenomenon connected to a specific critical sequence and the relationship between cause and effect.

The ***diagnosis*** is generally comprised by the experimental investigation (samples and tests) and analytical modelling (quantitative and qualitative) in order to interpret the pathology pattern and, then, formulate the diagnosis.

Both the experimental and analytical activities aim at better understanding the functioning mechanisms of materials and components, as well as the chain of events causing the decay. They help reduce the number of possible pre-diagnosis hypotheses and, eventually, validate them.

According to some authors, the wide availability of tools and devices and the complexity of masonry structures in historic buildings require, within the diagnosis phase, an independent sub-phase for the selection of the most suitable techniques.
Consequently, the diagnosis phase can be developed, according to figure 26.
Although the diagnosis phase is frequently underestimated, it is quite crucial for diagnostic validation, as well as for providing suitable input to the design and intervention phase.

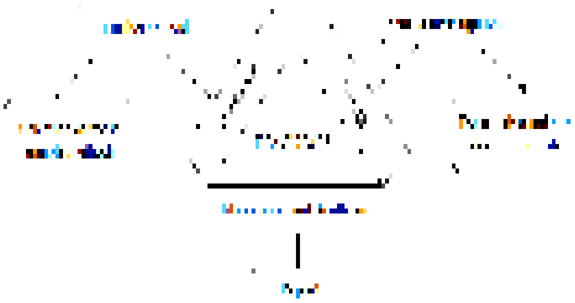

Figure 26 – Diagnosis phase

According to ASTM E 629, *Reporting opinions of technical experts,* the diagnostic report should be arranged, as follows:

a) Information on construction system, results from the preliminary survey and diagnostic investigation;
b) Diagnosis;
c) Diagnosis validation by analytical, analogical and experimental tools;
d) Intervention strategies, according to the physical structure under examination, detected pathology patterns and expected performance requirements.

3.3.3 INNOVATIVE ASPECTS OF INTERACTION WITH THE DECISION MAKING PROCESS

3.3.3.1 GENERAL ISSUES

The qualification of masonry structures – i.e. the system of information about history, materials, construction components, state of conservation, and residual performances – can only be achieved by means of a coordinated investigation methodology, that should take into account the complexity of construction systems and characteristics of existing buildings, and the process optimization, also in terms of cost, time and resources [Binda L. et al., 2000; Mc Cann D.M. et al., 2001; Schuller, M. P., 2003].

In fact, the state of the art reveals that methodologies and techniques for diagnosis in masonry buildings show a few critical issues:

— Testing methodologies are numerous, so their selection should be carefully made taking into account the main goals;
— Testing applications might require specialized operators that are only acquainted with specific techniques;
— Although destructive tests are necessary to calibrate the non-destructive investigation, they should be as limited as possible since they are quite intrusive;
— Testing the whole building is time and money consuming, so representative areas should be selected.

The above issues should be evaluated, also by considering: relevance of intervention, value of building, budget and deadlines.

As a consequence, an integrated system of tests is highly desirable to lead the professionals throughout the process, according to the following goals:

— Optimizing number and type of tests;
— Selecting specific investigation areas;
— Calibrating non-destructive tests;
— Allowing easy interpretation and correlation of results;
— Planning testing application including changes and/or iterations on the basis of results.

Consequently, two main issues can be found: on the one hand, the definition, by experimental testing, of operation and control methodologies for single diagnostic techniques, in terms of scientific validation, interpretation and correlation of results; on the other hand, the review of the knowledge process for masonry structures, in order to describe all the cognitive phases and integrate the contributions from upgraded diagnostic techniques and normative regulations.

3.3.3.2 STRUCTURE OF KNOWLEDGE PROCESS

There are several cognitive models (linear, iterative, feed-back based, and so on) not widely acknowledged by the scientific community. However, they all are based on analysis (where information is gathered and problems are detected) and synthesis (where solutions, models and networks are delivered).

Based on the research outcome, a flow chart is proposed (figure 27) where consequential steps are developed (vertical framework), based on input databases (horizontal framework). As a consequence, the flow chart outlines a logic path, where several decision-making steps are involved. Specifically, there are a few main tasks:

Basic Knowledge; Data Management; Preliminary Analysis and Pre-Diagnosis; Further Knowledge; Diagnosis; Project; Intervention; Intervention Assessment; Maintenance. Each task involves sub-tasks, which are in turn connected with data archives (handbooks of constructional typologies, materials, pathologies, cognitive methods and techniques) and normative references.

Data bases should be dynamic, so that all the information from testing and diagnosis can be uploaded/upgraded (dot lines in (figure 26). Moreover, they should be interchangeable, on condition that they are all implemented according to common guidelines and regulations, even if they come from different sources.

The technical normative database interacts with the decision flow in several points, which cannot be strictly identified, because regulations are lacking and are slowly updated and integrated, when compared to the technical evolution.

The above-described flow chart is a decision-making tool to select suitable diagnostic methodologies and techniques, according to reference parameters. Due to their complexity, the phases of preliminary analysis and pre-diagnosis are further detailed in the following sections.

3.3.3.2.1 PRELIMINARY ANALYSIS AND PRE-DIAGNOSIS

At this stage, survey of pathology patterns and mapping of materials and construction techniques are available as basic knowledge.

Materials and construction techniques should be thoroughly studied and analysed for all masonry components, based on the preliminary hypothesis about static mechanisms and pathology patterns. Handbooks of materials and masonry typologies should support such a sub-task.

The selection of reference masonry elements starts from mapping materials and construction techniques, in order to choose components that might be considered representative of the main masonry typologies in the building. As such, the analysis results for a reference element will be valuable for the whole typology. This sub-task should be supported by investigating areas where materials, morphology and construction techniques are homogeneous, leading to the assessment of Homogenous Comparison Areas.

As a consequence, the selection should consider whether:

- The areas are representative;
- The areas are well preserved (without cracking and dampness patterns);
- The tests are technically feasible.

If the above requirements cannot be met, preliminary tests to assess construction features of masonry elements are required, first following the section further knowledge (see next paragraph) and, eventually, going back to pre-diagnosis (figure 27). Then, a pre-diagnosis hypothesis can be formulated through analysis of pathological patterns – diagnostic tree – fault tree. The pre-diagnosis should point out whether or not the available information can lead to a reliable diagnosis. If the pre-diagnosis hypothesis is well supported, the diagnosis phase can begin and the diagnosis report formulated. Otherwise, reference masonry elements and pathological patterns should be selected for further investigation and interpretation.

3.3.3.2.2 FURTHER KNOWLEDGE

The macro task concerning further knowledge should focus on: physical and mechanical characterization of reference masonry elements, and additional investigation on pathological patterns that were not completely interpreted within the pre-diagnosis.

The analytical and experimental tasks at this stage (Definition of investigation areas, parameters and/or measures, Definition of investigation methods and techniques, Testing Programme and Application) aim at better understanding the functioning mechanisms of materials and components, as well as the chain of events causing the decay. They also help reduce the number of possible pre-diagnosis hypotheses and, eventually, validate them. The definition of investigation areas, parameters and/or measures should be carried out according to the knowledge scope and pre-diagnosis hypotheses. This task should be supported by databases. Moreover, checklists of the reference masonry elements, where all the quantitative and qualitative data is listed - both achieved and to be achieved - that might describe the relevant variables, should support it. Such checklists identify the current knowledge level and provide a systemic description of the element. For instance, the checklist of a masonry element requiring physical and mechanical characterization and identification of cracking/deformation tables, should include the variables that might cause the problem, i.e. internal causes, external causes, effects. The list can be adapted to each specific case.

The identification of relevant variables that need to be further investigated is quite crucial at this stage. Professionals (according to their expertise) should carry out the definition of investigation areas, parameters and/or measures taking into account:

- Relevance of cause/effect;
- Need of verification;
- Lack of available data;
- Danger conditions;

with reference to the defined tools and available databases.

The definition of investigation methods and techniques should start from databases of available technologies, considering the investigation areas/parameters/measures, as well as the material/constructional/technical features and conservation state of the reference masonry elements.

Once the investigation areas are defined, several tests are available to investigate the selected variables. However, tests are different, in terms of functioning principle, procedure, time and cost, output typology and reliability, and so on. The selection of testing methodologies might be very difficult, depending on the investigation complexity and extent. Moreover, in order to avoid unreliable and ineffective data, some elements should be carefully evaluated, such as:

- Reliability and extent of results, costs and resources of application, for each technique, also taking into account the investigated parameters;
- Possible correlation with results from different tests, especially when destructive and non destructive techniques are used;
- Reliability of each technique, considering materials, construction techniques and conservation state;
- Shortcomings for each technique.

The assessment of these elements leads to the selection of suitable methodologies and techniques. However, it is not clear for the operators, due to the complexity and relation of the involved aspects. The abovementioned tasks (definition on investigation areas, definition of methods and techniques) are strictly connected with one another. Moreover, they address the following task concerning the testing programme, where techniques and methods are selected, considering material and structural characteristics, technical reliability, feasibility and budget. This is the most delicate phase, which is still dependant on the professionals who might carry on the tests, regardless of the possibility to achieve a useful result.

In the light of the above-mentioned issues, an algorithm was defined (figure 28) that describes the steps to follow for the assessment of a suitable testing programme, including selection of investigation areas and tests. The methodology offers an analytic tool that can be used for a wide range of case studies.

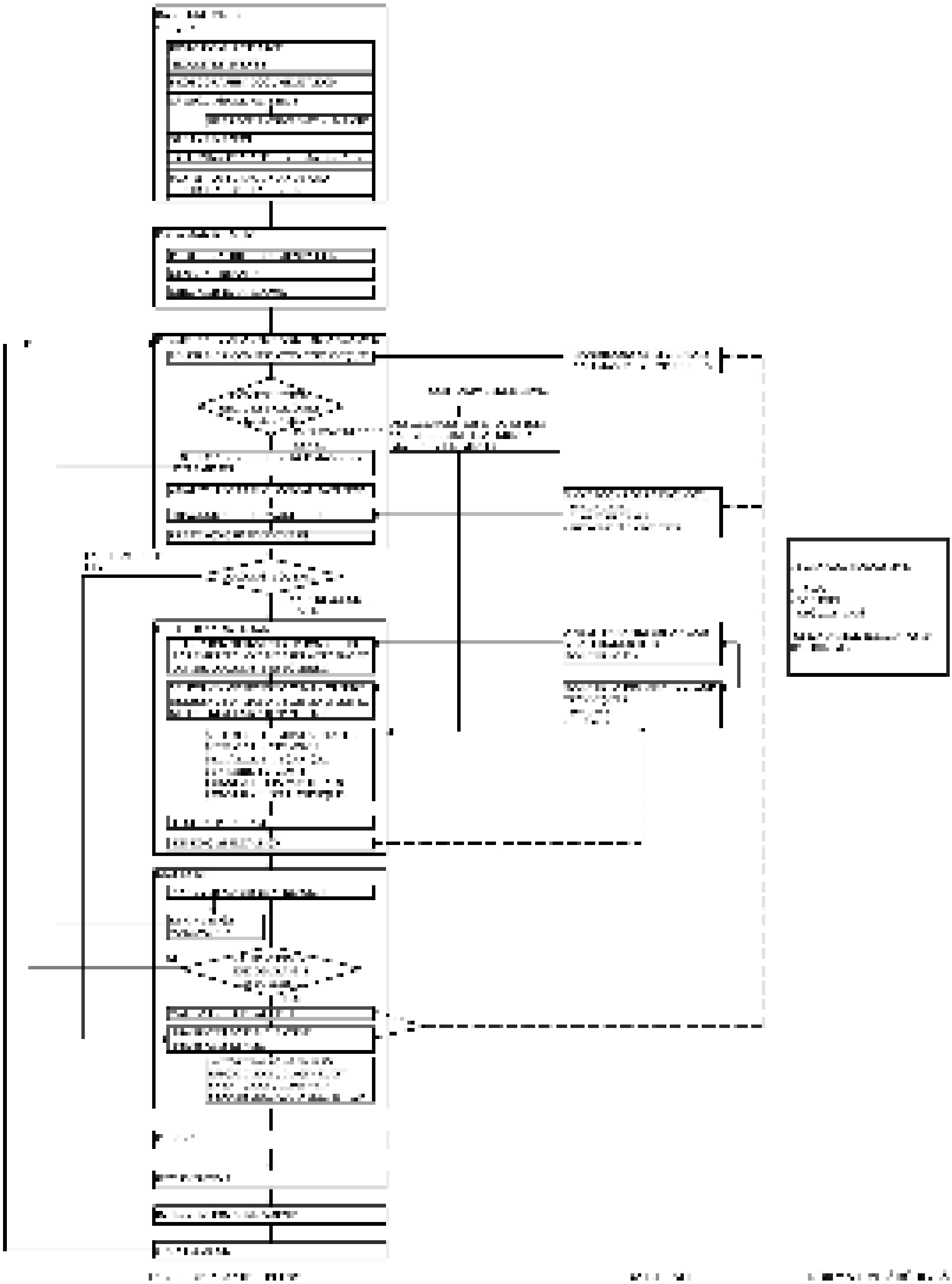

Figure 27 – Flow-chart of knowledge process

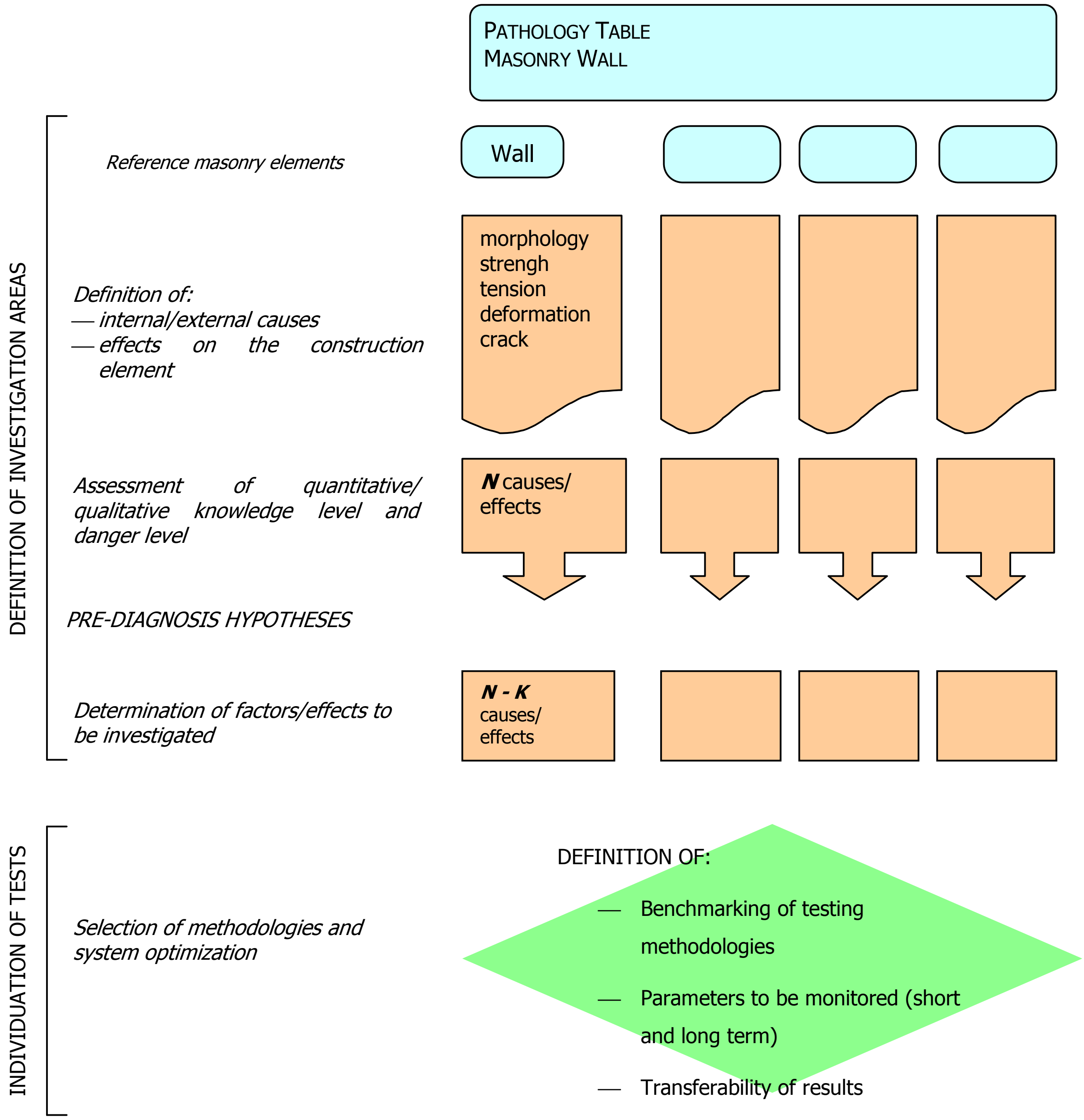

Figure 28 – General algorithm of testing programme

3.3.4 CONCLUSIONS

The flow chart that has been proposed as a diagnostic process framework for masonry structures, through a step-by-step logic procedure, can be certainly extended to different building typologies, even with with minor specific modifications. Moreover, it might be considered a review and update of the well-established model, developed within the previous W86 CIB State of the Art Report, which is still a valuable reference for the development of diagnostic activities. Particularly, the proposed approach meant to point out the relevance of knowledge, as a crucial preliminary phase of the intervention on built heritage.

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3.4 TRADITIONAL AND INNOVATIVE TECHNIQUES FOR MONITORING HISTORICAL BUILDINGS

(Mariella De Fino and Giambattista De Tommasi)

3.4.1 INTRODUCTION

When dealing with historical buildings, structural monitoring requires a preliminary knowledge, obtained through historical research, geometrical surveys, photographic documentation, mapping of materials and construction techniques, decay pattern surveys and geotechnical reports.

Nevertheless, laboratory tests for the mechanical, physical and chemical characterization of materials, and on site diagnostic methods have been more recently developed in order to overcome uncertain interpretations from the visual inspection of the building. Particularly, diagnostic procedures allows gathering relevant information such as:

i) Local execution of destructive and slightly destructive tests (sampling, single and double flat jack, hardness, penetration and pullout tests, endoscopy) provides quantitative data on mechanical properties, morphology and decay of materials and construction elements;

(ii) Global application of non destructive methods (thermography, sonic test, georadar) results in a comprehensive qualification of the structures, in terms of detection of hidden elements, mapping of structural discontinuities, assessment of the damage extent and analysis of the surface decay [Binda et al. 2000].

However, laboratory tests and on site diagnostic methods may be time and money consuming, as well as intrusive for the structural stability. Moreover, they may require control by skilled operators, interruption of operating activities, and mobility of heavy equipment. As a consequence, they should be carefully selected in order to provide significant and reliable results, to limit structural alterations due to non destructive tests and to relate the qualitative global information from non destructive tests with the quantitative local data from destructive tests.

As a result, similarly to the medical practise, all information coming from preliminary knowledge should address a preliminary diagnosis of the structural conditions, to be supported by specific investigation procedures, whose results will be correlated in order to achieve final diagnosis and analysis.

Once the diagnosis has been carried out, conservation measures can be scheduled. Nevertheless, before starting a project, a monitoring programme may be arranged in order to assess how structural conditions change along the time and whether restoration strategies are suitable and necessary, according to the actual behaviour of the system, including the structure and surrounding environment.

3.4.2 MONITORING HISTORICAL STRUCTURES

Monitoring concerns the collection of data on the evolution of key structural parameters, by means of on site devices, which may acquire continuous or periodic measurements. It should be planned considering all the useful information, previously collected in the diagnosis process, and eventually supported by computational models:

- To identify the time-zero configuration of the investigation;
- To assess the relevant parameters and points that the measures will refer to.

In fact, as the monitoring should alarm critical situations, it is important to know what is alarming and where a critical situation is expected to occur. The data from the monitoring will only be correctly elaborated if the threshold values are assessed. This assessment may be particularly challenging for masonry structures that generally undergo natural movements and settlements, due to thermal variations, humidity content and, ambient vibrations that do not affect their safety. As a result, the structural monitoring of historical buildings should also involve the detection of environmental parameters, in order to rule out any side effects.

A monitoring programme can be addressed to both static and dynamic control.

Static monitoring concerns the assessment of local cracks and deformation patterns' progression by means of displacement measurements, when structural settlings occur (buckling, side instability, rotation, vertical and horizontal translations) and the assessment of local strain trends by means of strain measurements, when significant stress variations occur (change in function, addition/demolition of structures, execution of restoration works);

Dynamic monitoring refers to the assessment of the structural response to surrounding conditions (wind, traffic, earthquakes, vibrating machines) and the structural characterization of the building by means of vibration measurements.

Static monitoring has been traditionally applied to the historical heritage. First, nogs and wedges for manual measurements, then fissuremeters, deformeters, extensometers and inclinometers for automatic detection have been widely used for controlling cracks and deformations on monumental structures. The Basilica of Santa Maria del Fiore, by Brunelleschi, has shown important damages since it was built in the 15th century in Florence, Italy. Within the dome, there are still some visible monitoring devices, which show the historical evolution of control systems along the centuries: from the dovetail stone tags to the computer based system that has been operating since 1988.

Nevertheless, electronic monitoring devices have been installed in several monumental buildings, like bell towers (the remaining five Towers of Pavia, after the Civic Tower collapsed in 1989 and the leaning Tower of Pisa) and cathedrals (Dome of Pavia, Church of San Vitale in Ravenna) in Italy.

Structural characterization is based on the analysis of the vibration response to a defined impulse, whereas the vibration response, namely natural frequencies, modal shapes and dumping factors, depends on geometry, physical and mechanical properties, as well as boundary conditions of the system.

Specifically, structural characterization should start with a preliminary dynamic test that can be used to calibrate the numerical models in order to assess their reliability. In fact, as the computational methods require actual input information, in terms of dimensions and constraints of the construction elements, as well as density, Poison's and Young's modulus of the materials, a semi empiric approach is proposed, in order to get a model that is as close as possible to the real structural configuration. First, the model is elaborated using data from the geometrical surveys, mapping of materials and construction techniques, decay pattern surveys, geotechnical reports, and laboratory and on site investigations. Then, a comparison is established between the vibration motion measured in the structure and the one calculated in the model respectively. Finally, input model parameters are iteratively changed, until the theoretical response is consistent with the experimental one. This approach is particularly useful for historical structures, whose modelling may be challenging due to the assessment of properties of materials and components, as well as of boundary conditions that may significantly change along the time.

As far as both static and dynamic monitoring are concerned, duration, frequency and devices are selected for acquisition of measurements and elaboration of results according to the objectives.

If the monitoring concerns the control of displacements, it is generally long term (up to several years) and low frequency (from every day up to every month), also considering historical data from foregoing investigations that allow at predicting the expected trend.

Devices may be very simple, as only a limited number of base measurements and readings are required. Manual equipments are less accurate, but, unlike automatic systems, they do not undergo the effects of decay, vulnerability to environmental conditions nor operation's interruption. Nevertheless, their sensitivity, ranging from one tenth of millimetre to one millimetre, is consistent with the relevant values that are supposed to be detected.

If the monitoring aims at assessing the response of the structure to stress/strain variations, it may be short term (but at least twelve months long, in order to take into account seasonal thermal variations), while the sampling frequency may be higher (at least a measurement a day). In this case, several measurements can be carried out in several points, in order to detect different responses within the structure and get a comprehensive understanding of the ongoing settling. As a consequence, automatic controlled systems are more desirable for data collection and correlation. Moreover, their high sensitivity of up to some microns can be useful, especially if computational models are used to assess the structural stability.

If the monitoring concerns vibration detection, it is generally short term and high frequency. In fact, the assessment of the structural response to surrounding conditions and the structural characterization are typically related to high magnitudes of the vibration source. As a consequence, the monitoring system is generally operating when the excitation (wind, traffic, earthquakes, vibrating machines) exceeds specific values. In this case, the devices should be very accurate and the process should be computerized as a wide set of data is required.

In the following section, a general overview of traditional monitoring systems is provided. Specifically, some of the most common control devices are described. Nevertheless, as the topic is particularly vast, the report aims at providing only some basic references in order to support and address further specific studies.

3.4.3 TRADITIONAL METHODS AND TECHNIQUES

Dovetail tags have been widely used for centuries to qualitatively control cracking propagation. A dovetail tag is a 10mm thick piece of mortar, bonded where the crack is wider, perpendicular to the crack direction. The piece is double dovetail shaped in order to bond the tips to the structure. The application date is registered beside the tag and two pencil markings are made at the top and bottom of the crack. A tag should be controlled periodically to check if it has broken, which would correspond to the crack widening, or if it has extended beyond the pencil markings. A tag should not be made out of cement mortar, because it could be affected by shrinkage, nor glass, since it is very fragile and sensitive to temperature changes. If the tag is applied on the inside, plaster and common lime are generally used. If it is applied on the outside, water-based lime is more suitable for resisting from environmental conditions.

Fissuremeters (figure 29) measure horizontal and vertical displacements between two base points, with 10E-1mm accuracy. They are composed of two overlapped transparent plastic plates. The top plate shows two orthogonal axes. The bottom plate has a grid divided into millimetres as a graph paper. Before monitoring, the two plates are stuck to each other with adhesive tape to rule out small movements due to the installation. Specifically, when the gauge is set up, the origin of the two axes above should corrispond to the centre of the grid below. Each plate is connected with one of the two measurement bases. Then, the adhesive tape is removed and the two plates can move freely according to the movement of the two points of the structure they are connected to. Readings can be taken manually.

Deformeters or Mechanical Extensometers (figure 30) measure the displacement between two base points with 10E-3mm accuracy. They are composed of a metallic tube made out of invar steel, in order to reduce the thermic expansion of the gauge, which may affect the results. Two tapered pins are mounted at the tips of the tube. One pin is fixed; the other can move along the tube, up to ±5mm. Displacement value and direction are detected by a comparator and transmitted to a reading unit that can be analogical (display with pointer) or digital (LCD display). Measurement bases can be up to 2E+3mm distant. Two steel plates are bonded by epoxy resin to the structure. The plates show a small conic cavity on the external side for anchoring the tapered pins.

LVDT's (Linear variable differential transformers) (figure 31) are sensing devices that produce an output voltage proportional to the mechanical displacement of a magnetic core. They are composed of a metallic hollow cylinder, where a primary and two secondary coils are symmetrically arranged, and by a nickel-iron core, supported by a nonmagnetic push rod. The metallic cylinder is fixed to the structure by suitable pins, while the magnetic core may move axially within the cylinder in response to mechanical displacement of the probe tip that is also connected to the structure,. With excitation of the primary coil, induced voltages will appear in the secondary coils. Because of the symmetry of magnetic coupling to the primary, these secondary induced voltages are equal when the core is in the central position.

However, if the core is displaced from the central position, in either direction, as a result of movements, one secondary voltage will increase, while the other decreases. Since the two voltages no longer cancel each other, a net output voltage will now result. Specifically, the output will be proportional to the magnitude of the displacement, with a phase polarity corresponding to the direction of displacement. LVDT's are very accurate, as they are not affected by friction. Moreover, they show good resistance, reliable repeatability of the zero and absolute measurements.

Strain gauges (figure 32) measure local strains with 1$\mu\varepsilon$ accuracy. They are composed of an insulating flexible backing which supports a metallic foil pattern consisting of thin wires (diameter of 2E-1mm) arranged as a coil. The gauge is bonded to the structure by epoxy resin. If deformation occurs in the structure, it will be transmitted to the foil. As a consequence, the electrical resistance of the gauge will change. This resistance change, usually measured using a Wheatstone bridge, is connected to the strain by the gauge factor and is a result of the relation between the electrical conductivity and the geometry of a conductor.

Figure 29 – Fissuremeter by Durham Geo

Figure 30 – Deformeter by Huggenberger

Figure 31 – LVDT's by Bestech Australia

Accelerometers (figure 33) measure accelerations. They consist of a mass connected to a spring and a sensing element, hosted in a metallic box that can be bonded to the structure by epoxy resin. The mass produces a force if it is accelerated (F=ma, Newton's law) and the force produces a deflection in the spring (F=kx, Hooke's law). By measuring the deflection, the acceleration can be calculated (a=kx/m), if m (mass) and k (spring elastic constant) are known. Different accelerometers are available according to the physical principle and the sensing element to determine the spring deflection. The described system is a single axis accelerometer, as it only responds to accelerations along the length of the spring. In order to measure multiple axes of acceleration, the system needs to be duplicated along each of the required axes.

3.4.4 FROM MONITORING TO STRUCTURAL HEALTH CONTROL AND DAMAGE IDENTIFICATION

Structural health control concerns use of on site measure and analysis of structural parameters under operating conditions, for the purpose of warning impending damages at an early stage, as well as giving maintenance and rehabilitation advice [Housner at al. 1997]. Specifically, measurements are local, but they can provide information about the global system because structural and environmental parameters are detected for a significant number of points throughout the service life of the structure. Structural health monitoring is connected to the damage identification, as a comprehensive data acquisition may allow for assessing local anomalies within the global structural configuration.

The approach is deeply innovative compared with traditional monitoring. Traditional static and dynamic monitoring is focused on visible anomalies that appear when the damage has already developed into an advanced stage, and to specific surrounding events that are considered dangerous. On the contrary, structural health control refers to a damage condition before it develops into visual detectable alterations and disturbing effects. As a result, it allows for a preventive and predictive control strategy along tspace and time.

Structural health control is particularly attractive for the conservation of the historical heritage, whose damage mechanism is generally uncertain and unpredictable, especially due to the variety and complexity of construction typologies. In fact, numerical models developed to theoretically predict that mechanism are often ineffective, as they were first developed for modern materials and they require a few simplifications when applied to historical structures. As a consequence, they can lead to interventions that are often restrictive, protective, and even inappropriate, whereas the solutions are supposed to produce reversible and non-invasive alterations to the buildings.

Control of actual structural parameters may positively affect the structural safety: it may face the vulnerability of historical buildings that have recently undergone sudden collapses, due to physical decay, missing maintenance or uncontrolled surrounding conditions, without showing visible alerting

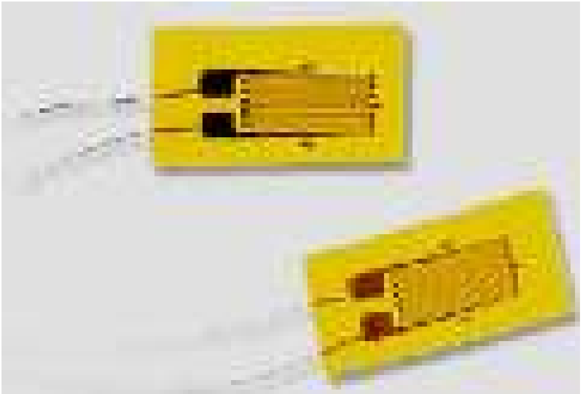

Figure 32 – Standard strain gauge by Omega

Figure 33 – Standard accelerometer by Honeywell

signs (Civic Tower of Pavia, Bell Tower in Venice, S. Maria degli Angeli Basilica in Cuneo, Cathedral in Noto) and it may enhance the seismic protection that is still critical in many cases (Basilica of S. Francesco d' Assisi). Nevertheless, it may be helpful for scheduling rehabilitation interventions that are indeed necessary, so as to avoid useless and ineffective transformations of the original historical, architectural, functional and technical identity of the buildings. Moreover, a predictive control may play an important role while, and after carrying on conservation works, as it may allow knowing the structural response to the execution phases, by checking the short term expected results and the mid term evolution of the overall parameters within a modified structural configuration.

Within this scenario, some innovative approaches have been under development for some years that basically refer to:

(i) integration of sensor systems for direct measurements of physical, mechanical and chemical parameters, both static and dynamic;
(ii) application of non contact techniques for the detection of vibration motions.

The first approach concerns innovative systems, commonly known as smart, namely piezoelectric and magnetostrictive, MEMS and RFID, as well as fiber optics. They are all small, light and resistant. They can be permanently embedded into the structure, in order to gather local information that is addressed to remote data platforms by communication networks [AA.VV. 2002]. The latter approach is based on laser interferometry technologies that allow for detecting vibration velocities of moving surfaces using a focused laser beam, in order to get the global system dynamic identification. All these technologies may lead to distributed and repeatable mapping of the structural configuration and to detection of anomalies throughout the space (local damage) and time (impending damage). Some general information about them is provided in the following section.

3.4.5 INNOVATIVE TECHNOLOGIES

Fiber Optics is one of the most promising technologies for structural monitoring. They are dielectric light carriers that can be mounted on the surface or integrated into the material. From an input electric signal, a light is emitted by a laser source, passes through the fiber, is detected by an optic receiver and finally converted into an output electric signal. The variation of the electric signal, namely the light properties, along the fiber connected to the structure, can be valuated in order to gather information about the state of the structure, in terms of strain, stress, vibration, temperature, humidity, chemicals and to detect anomalies and defects.

Fibers transmit electromagnetic waves with low losses. They are made out of two concentric layers: a central cylindrical core and an external cladding. Total diameter is typically 125 µm. The external layer is realized with lower refractive index than the internal core, so that the light is kept inside according to the total refraction principle, unless the fiber does undergo a sharp bend [Gandhi 1992].

Fiber optics present several advantages:

- Small and light, so that they do not alter the structural integrity.
- Resistant in harsh environmental conditions.
- Undergo processes with very high pressures and temperatures.
- Immune to electric and electromagnetic interferences.
- Compatible with ordinary telecommunication fibres.
- Don't show significant signal attenuation.

There are different technologies based on fiber optic sensors, according to the investigated light property and the exploited physical principle [Nezih 2002]. Nevertheless, they can be all grouped into three categories, in relation to the pattern of sensors along a single fiber:

- Local sensors, where the measure concerns a single area that is generally several centimetres long over the fiber (for instance, interferometer sensors);
- Semi distributed sensors, where the measure concerns several portions, generally one millimetre long each, over the fiber (Fabry-Perot and Bragg grating sensors);
- Distributes sensors, where each point of the fiber is sensor active (Raman and Brillouin sensors).

These patterns correspond to different methodological approaches. Particularly, semi distributed and distributed sensors go towards a widespread monitoring involving a significant number of points during the whole life cycle of the structure. They perform when the structure is under working conditions and they can detect, or even predict, some anomalies before they produce damage. Applications of semi distributed and distributed technologies are basically referred to steel, reinforced concrete and fiber composite structures. In a few cases, they have also been used for historical buildings, like Dome of Como [Albrecht et al. 2002] and Palazzo Elmi Pandolfi, Foligno, Italy [Bastianini et al. 2005].

Figure 34 – Example of MEMS

Figure 35 – Single Point Laser Vibrometer by Polytech

MEMS (figure 34) are microelectromechanical devices that generally comprise micro sensors, signal processing units and micro actuators integrated on a single small size silicon chip by means of the so called micromachining process. They can be bonded onto the structures and integrated into materials.

The micro sensors collect information from the environment. Specifically, they convert a mechanical/thermal/chemical input into an electric output due to the properties of the materials they are made out of. In fact, components that show piezoelectricity (capability to produce an electric field from a mechanical force), piezoresistivity (capability to undergo a resistivity change from a mechanical strain) and thermoelectricity (capability to produce an electric field from a thermal variation) are generally used. The signal-processing unit processes the information and provides an input to the actuators. The actuators, in turn, can start up an action to compensate for the detected change. If MEMS are just sensing systems, the actuators are left out and the signal-processing unit transmits the information to a base station connected to a computer for data elaboration. Particularly, as these systems are generally equipped with radio modules and antennas, they allow wireless communication.

MEMS technology has been successfully applied to civil infrastructures [Saafi & Robinson 2006]. Nevertheless, as MEMS devices are typically on the scale of a few microns in dimension, they allow distributed sensing and acting capability, as well as redundant space and time data collection, which are also potentially desirable for historical buildings.

Laser vibrometers (figure 35) are innovative devices, which many studies and experimentations are focused upon, also with reference to building materials and structures [Copparoni et al. 2003 & Agnani et al. 2005]. Specifically, laser vibrometers allow for detecting the velocity of a moving point focused by a laser beam. The device measures the frequency shift of the laser beam, scattered back from the vibrating surface, according to the Doppler Effect. Light beam from a laser source is split in two same power beams by a splitter. One of the two, called "measuring beam", is focused on the vibrating surface. The other one, called "reference beam" is housed in the laser head. After being reflected, the measuring beam enters back the laser head. Here, it is recombined with the reference beam. Surface displacement alters the optical path difference between the two laser beams. This difference results into a phase lag varying with vibration velocity (v). Specifically, the frequency shift is equal to the Doppler shift (fD) that depends on v and source wavelength (λ). Then, it is possible to extract the velocity v, by demodulating the output signal.

Laser vibrometry devices are different for operation modes and performances. A common classification refers to:

- Single point vibrometer - allows at measuring the velocity only in one point;
- Differential vibrometer - detects the relative velocity of two points;
- Scanning vibrometer - measures velocities for a significant number of points and gives a global mapping of the investigated surface.

Most diffused Laser Vibrometers have a maximum velocity range of 10 m/s, with a frequency upper limit of 200 kHz, a resolution of about 1μm/s and a base accuracy in the order of 1%-2%. Nevertheless, operating distances of tens of meters are possible with a spatial resolution of 1mm.

From the operating point of view, laser vibrometry shows different advantages over conventional vibration measurement systems:

- Simple to use, quick and portable;
- High sensibility and ample frequency response;
- Allows remote measurements that are particularly useful when contact devices are difficult to apply, due to high temperatures, low accessibility of the area, physical vulnerability and formal value of the surface;
- Leads to significant time and cost savings, especially if the survey concerns an extensive grid of measurement bases and/or an intensive periodicity.

Nevertheless, this technology can be even less intrusive if it uses non contact excitation systems, namely environmental sources (traffic vibrations for bridges, bells for towers, organs for churches) and artificial sources (loudspeakers).

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3.5 ASSESSMENT OF IN USE PERFORMANCE PARAMETERS OF RENDERING FAÇADES

(Inês Flores Colen, Jorge de Brito and Vasco Peixoto de Freitas)

3.5.1 INTRODUCTION

Condition Assessments are required throughout the life cycle of the building façade, and are an important tool to improve the knowledge of in-service conditions and helping the inspectors in maintenance planning. A condition survey is defined by RICS (1997) as "the collection of data about the condition of a building, estate or portfolio; assessing how that condition compares to a pre-determined standard, to identify any actions necessary to achieve that standard now, and maintain it there over a specific time horizon, the purpose being to support management decision making". Conditioned-based maintenance by performing inspection assessments has been for some time a useful tool for reducing life cycle costs and finding more efficient ways of using maintenance budgets (Hertlein 1999), and it is also an appropriate maintenance strategy for elements whose condition can be suitably monitored.

In this context, condition assessment of rendering façades should compare required performance level with supplied performance level, on a practical and unambiguous basis, in order to help the serviceability assessment and maintenance planning of rendering during the post-occupancy stage. The application of rendering on-site performance assessment has been difficult due to several reasons: design solutions are mostly prescriptive instead of based on performance assessment criteria; technical data provided by the manufacturers is insufficient or descriptive; and legal requirements (EN 998-1) are not enough to evaluate its global performance. Therefore, condition assessments have been restricted to visual inspections, without quantitative parameters through testing techniques and without systematic methodologies in the majority the cases, which has led to a deficient diagnosis and consequent implementation of inadequate maintenance interventions. The usual absence of records of intervention (historic of the building) and means of access in the buildings aggravate this situation through an accumulation of errors.

In literature, several methodologies have been used for field condition assessment of cement-based rendering façades, such as: the study of one-coat render adherence to the substrate using accelerated lab testing (Freitas et al, 2008); definition of visual scales in terms of type and extension of anomalies with indicator of degradation (Gaspar & Brito, 2005, 2008; Shohet et al., 2002); the application of factorial method for performance assessment of plaster and paint applied on façades (Chew & De Silva, 2004).

This contribution intends to present a methodology that was developed within the PhD of the first Author in order to improve inspections' diagnosis during façades' service life, in terms of degradation, performance and maintenance criteria. Therefore, a set of in-service parameters (visual observation and measurements) and their methods of assessment (based on visual inspections, auxiliary techniques, in-situ and laboratorial testing) are included in this methodology through the inspections of 44 case studies of rendering current buildings' façades (with cement-based renders, mixed on-site or pre-mixed in a factory), with different ages and types of degradation. Finally, the reliability of this in-service performance assessment is discussed and also its potential application in decision-making of predictive maintenance actions (actions that are the result of inspection's diagnosis).

3.5.2 RENDER CONDITION ASSESSMENT

3.5.2.1 REQUIRED AND SUPPLIED PERFORMANCE

Rendering condition assessment, based on technical in-service assessment, must define the problem, collect available data, characterize existing anomalies (Flores-Colen et al., 2008a) and their probable causes, evaluate in-service performance (fulfilment of the functions established at design), check whether user's demands are being fulfilled and define corrective, preventive or monitoring maintenance actions. The comparison of required performance level (the minimum performance level that must be provided at a certain moment in time) with supplied performance level (the maximum performance which can be provided by a building component at a certain moment in time) over time can be made if supply and demand for components are expressed in the same way. Figure 36 shows the proposed relationship between demand and supply sides, when a rendered façade condition assessment is made through visual observations, in-situ and lab testing, based on the

Conceptual Framework for the Whole Life Cycle of Facilities (Szigeti & Davis, 2005).

The required hardened properties rendering mortar (required performance criteria) are established by European standard EN 998-1 (CEN, 2003) (rendering mortars based on inorganic binders use on walls with different fields of use and exposure conditions), and complemented by other technical issues; these properties are assessed through laboratory tests using standard apparatus and specimens. According to Hermans (1995) the supplied performance level has to be determined on-site (it is affected not only by design decisions, but also by construction process, material characteristics, its shape and location in façade) and contains a set of performance levels belonging to various performance categories at a certain moment. The author also compares deterioration with performance "the term deterioration is connected to the change of the characteristics, instead of to the change of the performance level itself". Thus, it is important to recognize that some cases of reduction of properties do not affect critical aspects of performance.

In fact, in-situ techniques are usually focused on elements' degradation and do not provide a direct correlation with the previous performance requirements. Therefore, the control of in-use performance requirements has been difficult to implement, leading sometimes to a deficient diagnosis or implementation of inadequate maintenance interventions.

Research being carried out on several types of façades renders collected a set of techniques to be applied on in-service performance evaluation of rendering façade. Some of these techniques have been used in other buildings elements, e.g. concrete or timber structures, landing mortar in brick blocks, or renders/plasters on ancient walls. Most of them are not standardized; the criteria to assess and interpret the testing results are missing, despite some of them having technical procedures (RILEM or LNEC, 2005, among other publications). According to ISO 15686-2 (2001) "many of the standardized inspection techniques suffer from the fact that they rely upon subjective judgments of the practitioners. This makes comparisons between studies from different practitioners less reliable; …there is a need for further development in this field and the standardization of existing, more sophisticated techniques".

In this methodology the application of in-service performance profiles (IPP) are recommend. The IPP include in-service performance indicators and reference values of properties measured on-site (reference IPP); in figure 36 three performance categories are exemplified: surface condition, mechanical strength and water resistance for condition assessment in current area of rendering façade. Conditioned maintenance should be applied when the supplied in-service performance level (at least in one of the three previous categories) is not acceptable, through cleaning, repair, replacement and protection actions. For example, using mechanical strength indicators, the use of an in-service performance profile (IPP) in serviceability assessment is possible with the identification of a reference IPP that considers two groups of renders (A and B), taking reference values (as shown in figure 37; in this example, the ready-mixed mortars PL belongs to group A and PP to group B). This profile allows the integrated study of more than one on-site property and therefore it can increase the reliability of the assessment.

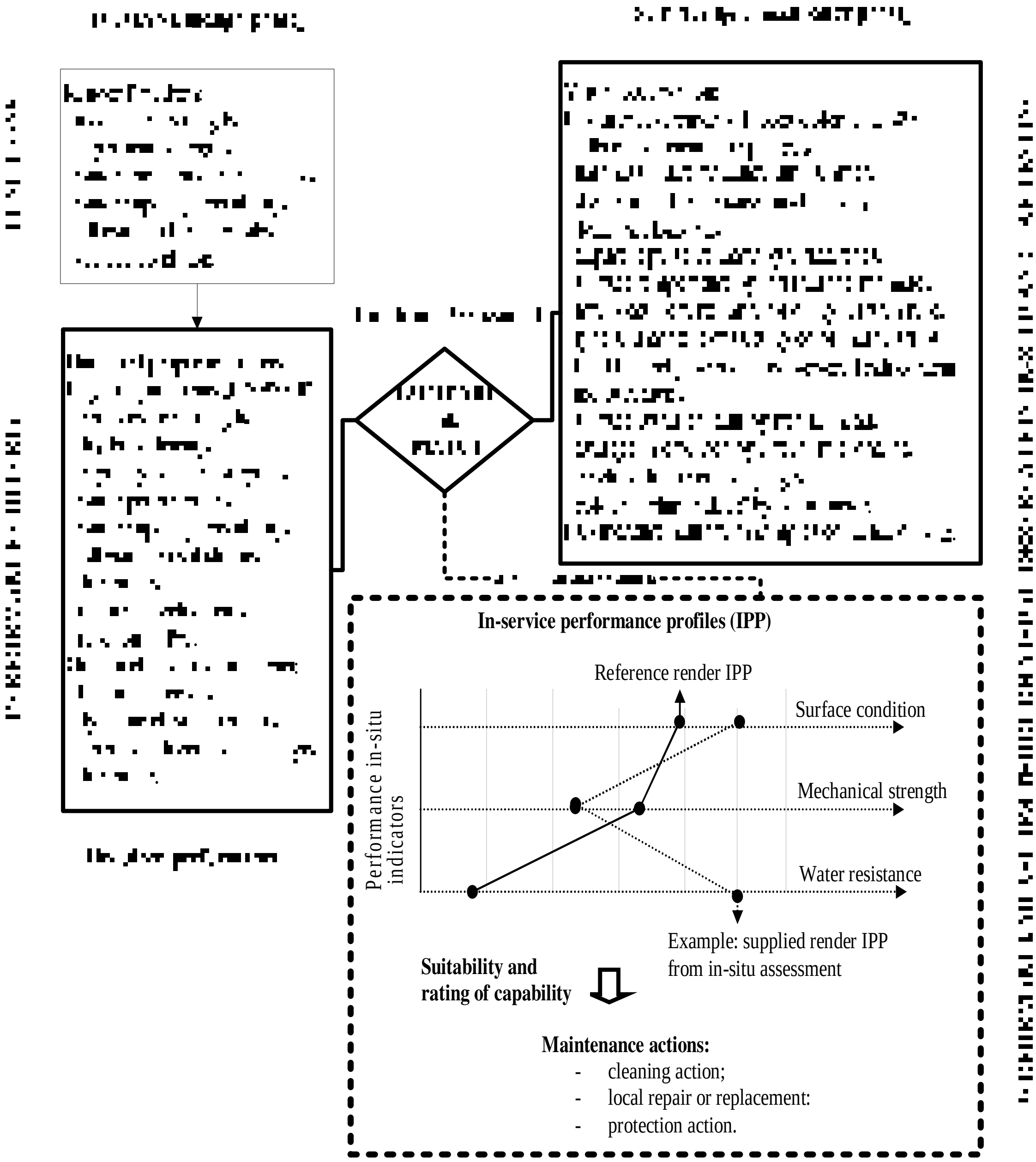

Figure 36 – Methodology for condition assessment of rendering (Flores-Colen, et al., 2008b).

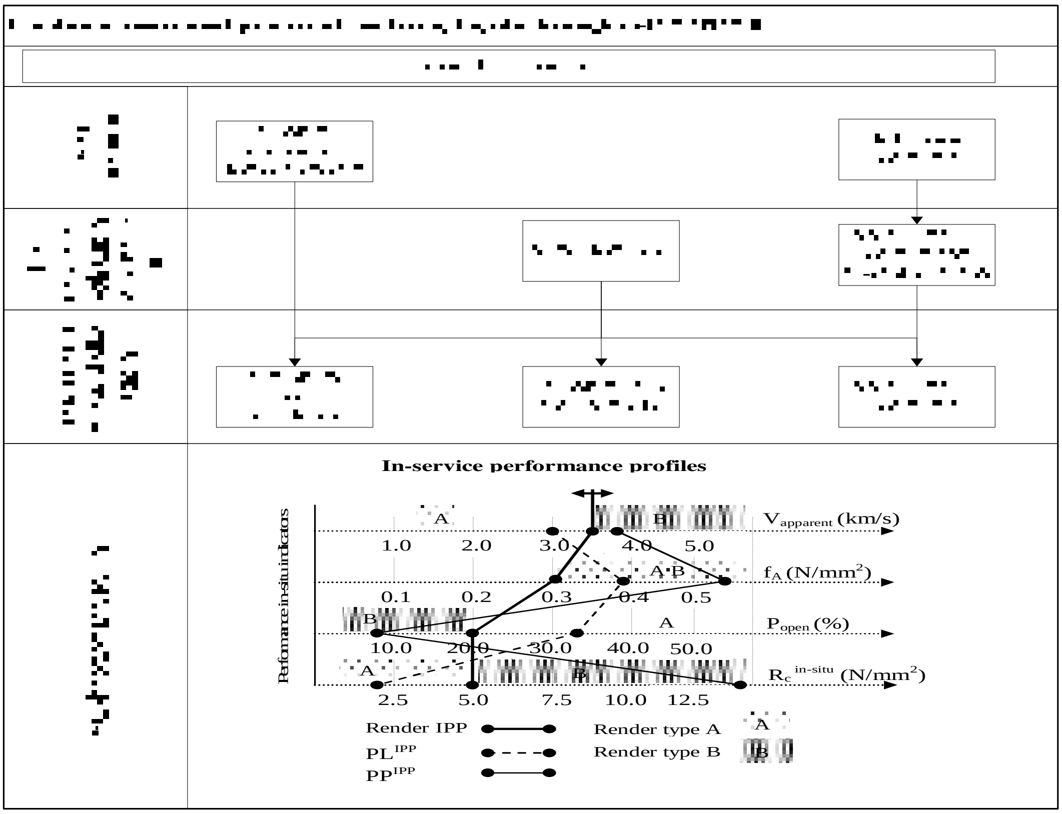

Figure 37 – Example of condition assessment of rendering trough hierarchy on-site mechanical strength indicators.

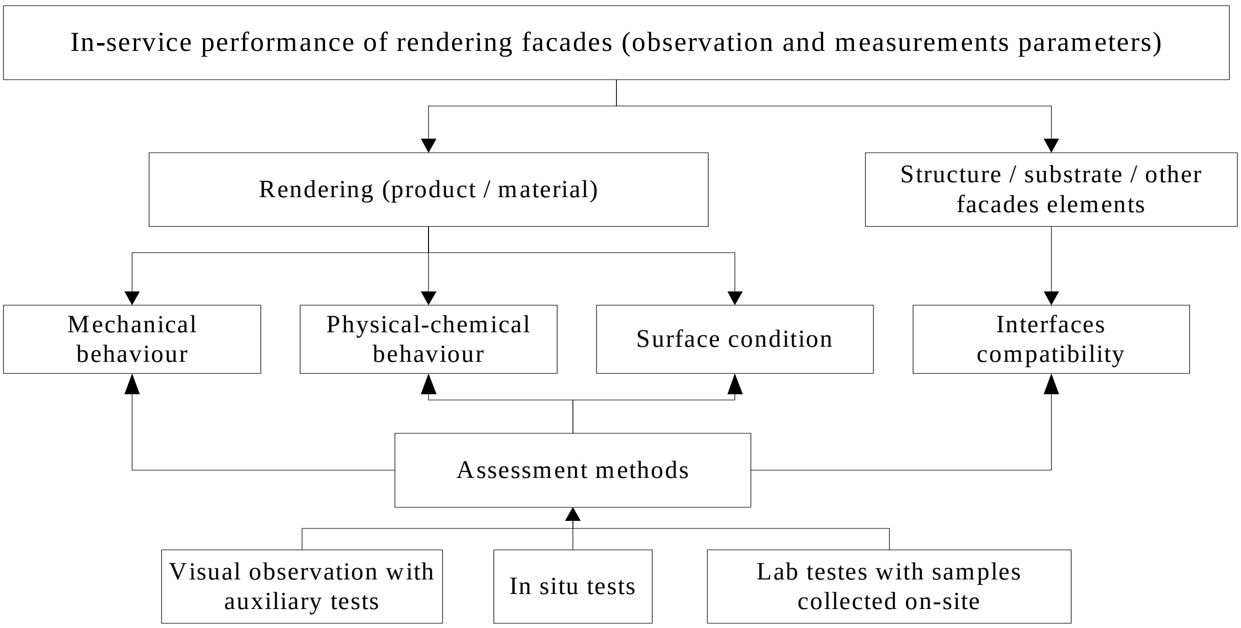

Figure 38 – Performance criteria and methods of assessment (Flores-Colen, et al., 2010)

3.5.3 CRITERIA AND TECHNIQUES

The proposed methodology includes four types of performance criteria assessment (multi-performance approach): 1) condition of the rendering surface (in terms of anomalies and inner heterogeneities); 2) compatibility of interfaces (identification of problems in render with the other elements of façades, such as wall, structure, finishing layer, copings, sills, among others); 3 and 4) mechanical and physical-chemical behaviour of render. The assessment methods proposed in the methodology include visual observation, auxiliary methods, in-situ and lab testing (in this type of assessment samples are collected on-site), figure 38.

3.5.3.1 SURFACE CONDITION

The surface condition parameters included visual assessment of anomalies (stains, cracking, detachments, loss of cohesion) and the usage of techniques with low intrusive degree on the rendering wall for performance assessment: [internal heterogeneities (ultra-sound and Schmidt hammer); homogeneity of color and gloss (chromatic NCS scales, gloss measurer); homogeneity of texture (measurer of roughness); geometric deviations of flatness and verticality (ruler of 3 meters and plumbline)]. These parameters can identify the need for further diagnosis, in terms of the mechanical, physical or chemical behaviour of the applied render in service conditions.

3.5.3.2 MECHANICAL PERFORMANCE

The mechanical in-service parameters include measurements directly on the rendering [adherence strength (pull-off test); apparent ultrasonic velocity (ultrasound equipment); sclerometer index (Schmidt pendulum hammer); diameter of the dent and mass index of cut-off impact (Martinet Baronnie equipment)]; and also measurements on samples collected on-site: [apparent bulk density and open porosity (hydrostatic weighing); compressive strength (compression test)]. Next, the main aspects of each parameter are briefly discussed.

Apparent bulk density is a parameter with limitations in terms of applied products distinction, despite having a good correlation with mechanical parameters in lab experiments. In-situ results have shown higher values than the ones expected for one-coat renders (this can be related to the influence of execution procedures in the compacity of mortars, such as mechanical application and quantity of mixing water) (Fernandes et al., 2005).

Apparent porosity is a relevant parameter when how the render was applied to the façade is unknown since it allows telling apart the two groups of renders (ready-mixed and traditional mortars) (Flores-Colen et al, 2008b). Lab experiments have shown good correlations with open porosity and the following parameters: apparent bulk density, compressive strength; flexural strength; dynamic elastic modulus; and water vapour permeability. Additionally, good correlations with this parameter and sclerometer index and drying index were determined in in-situ results. However, the relation of this parameter with certain anomalies (e.g. loss of cohesion) needs further research.

The adherence strength is a standard parameter. Even though it is not enough to distinguish products, it can complement the diagnosis as a probing technique (providing a better knowledge of the render's coats or type of substrate) (Flores-Colen et al, 2009), leading to other parameters characterization, namely mechanical parameters (compressive strength obtained from 10*stress in cohesive failure; and compression test on samples), or physical-chemical parameters through sampling tests. The limitations of this parameter are the additional works to repair tested areas and prepare the cores (heating process to remove the metallic peace used in pull-off test). The two previous parameters to obtain compressive strength indicators have shown, in lab testing, good correlations with compressive strength in standard specimens. Despite that, these parameters have demonstrated some difficulty of in-situ results interpretation, and therefore other testing and sampling factors may have contributed to this situation: high degradation and low thickness of samples tested.

The apparent ultrasonic velocity gives information about inner render heterogeneities, especially cracking or voids with air. The in-situ results have shown that there is a relation between the decrease of the apparent velocity (when compared with the velocity measured in areas without visible problems) and the type of anomalies (for example, micro-cracking with 0.05 mm and surface loss of cohesion led to a 10% decrease and significant loss of cohesion have led to a 40 - 50% decrease). The in-situ results have also confirmed that this parameter is influenced by the surface moisture, and therefore high moisture values can increase the results of velocity, and mask the results. Additionally, and according to the lab testing, this parameter is also an indirect measure of dynamic elastic modulus.

The correlation of sclerometer index with compressive strength, in standards specimens, was established after systemization of several studies performed by other researchers. However, in-situ results have shown higher values of this index due to the influence of the substrate. In-situ correlations between this parameter and apparent bulk density, open porosity, diameter of the dent, allowed the definition of criteria for render applied on a wall for in-service conditions.

The diameter of the dent is a parameter that gives indirectly the resistance to the surface deformability of the render (Flores-Colen et al, 2009b). In lab experiments, several correlations were obtained with this parameter and other mechanical parameters, such as: apparent bulk density and apparent ultrasonic velocity. In field campaigns the correlation coefficients were lower. This parameter depends significantly of the texture of finishing layer and can be insufficient to evaluate render applied in public areas or with risk activities (e.g. playing area), since the impact will be higher than the one that is evaluated with this technique (3 J). In this context, it is better to express this parameter in function of impact energy and depth of denting, to compare different techniques of assessment. The mass index of cut-off impact does not add significant information when compared with the diameter of the dent.

3.5.3.3 PHYSICAL-CHEMICAL PERFORMANCE

The physical-chemical parameters include measurements directly on the rendering: [surface moisture (moisture meter); surface temperature (radiation pyrometer); absorption coefficient under low pressure and water permeability at 48h (Karsten tube)]; and also measurements on samples collected on-site: [capillary coefficient and water content at 48 h (capillary absorption test); initial velocity of drying and drying index (drying test after capillary absorption test); chloride, nitrate, sulphate concentrations (kit for salts); pH and conductivity (portable measurer)]. Next, the main aspects of each parameter are briefly discussed.

Surface moisture is measured by a non-destructive technique and therefore moisture mapping on surface can give relevant information, such as the resource of moisture and its effects-gravity (e.g. values below 11% without any anomalies; values between 21 and 51% with biological colonization, in drying inspection conditions). In-situ results have also shown that higher surface temperature can reduce measured values of surface moisture.

Surface temperature can be important to understand hydrothermal behaviour, such as the occurrence of condensation on the render surface. However it needs a longer period of analysis (24h) than the one currently used in a daily inspection (maximum of 8 h). This limitation is also applied on the assessment of water permeability at 48 h using Karsten tubes.

The absorption coefficient in Karsten test can give sound information on water permeability; despite the technique limitations (e.g. surface finishing and degradation can restrain the application of test's tubes). This parameter showed good correlation with capillary coefficient in samples, in lab and in-situ experimental tests. In conclusion, the capillary pores have also an important role in the resistance to water penetration, even with pressure gradient. This aspect is only valid in the first 60 min, after which the water penetrated due to the pressure gradient is higher that the capillary water absorption and no relations can be made.

The capillary coefficient in samples can distinguish products because the pre-mixed mortars usually have hydrofuge in their formulation. This parameter should be determined by the slope of the linear function between mass variation and square of time in capillary absorption test. The difference of the mass at 90 and 10 min (equation from EN 1015-18) does not consider different contact areas of samples with the water and different behaviour due to different pore structure. The water content at 48 h in the capillary absorption test can complement the diagnosis when the previous parameter is inconclusive (e.g. in traditional products, small samples with low thickness can rapidly saturated and invalidated the capillary coefficient determination).

The drying index is a parameter that can be relevant for in-service assessment. In-situ results have shown its relation with apparent porosity, allowing the water vapor permeability extrapolation (in lab experiments. The initial drying velocity was inconclusive with these experimental testing. Salts content can be correlated with the surface moisture. The in-situ results have shown good correlation between surface moisture and hygroscopic salts: chloride and nitrate content, in a polynomial of 2nd degree (above 50% of surface moisture, high values of salts content were also measured). The determination of sulphate concentration has given a significantly number of low or nil concentration values. These limitations can be due to the method of assessment (one of the reagent does not react with the calcium sulphate that also has a low solubility in the water).

The pH value can give information about chemical reactions, such as carbonation. However, it is not enough to interpret in-situ results, and depends on the renders' condition at the time of the measurement (if at this instant the balance is not stable, the value of pH will change). Conductivity can be related with pH (one ion can have different conductivities for different pH solution values) and salts existing within the render (not only the ones that were assessed). Therefore, the in-situ results were inconclusive despite the correlation between this parameter and chloride concentration.

3.5.3.4 INTERFACE COMPABILITY

The interface compatibility is assessed, at the first stage, through visual observation during the inspections. The parameters of interface included the interaction between the render and its background/structure, finishing and also between render and other facade's elements such as coping, sills, among others. The classification of each interface parameter includes the degree of intervention to solve the incompatibility and also the initial cost in terms of the initial application of the render.

This type of assessment adds eventual limitations to interventions, because it can lead to limited in-service diagnosis (sometimes the causes of anomalies are related with other elements of the façade, for example foundations / structure, that increase significantly the cost of the interventions but are not included in the analysis), and the success of interventions can be compromised.

3.5.4 RELIABILITY OF IN SITU ASSESSMENT

The results have shown that the integrated study of more than one parameter has improved the knowledge of in-service – surface condition, interfaces compatibility, mechanical characteristics (internal or cohesive strength; adherence to the support; deformation capacity and surface resistance) and also physical-chemical characteristics (resistance to water permeability; resistance to moisture; hydrothermal resistance; biological and chemical resistance). For example, internal discontinuities of the render were detected by ultra-sound tests and also confirmed by the week resistance of the render. In spite of, further investigation need to be made, for example in terms of the factors that can influence compressive testing in samples, or the creation of new parameters that can measure on-site the restrained shrinkage and deformation capacity.

Additionally, some aspects have been adapted to facilitate in-situ procedures: 1) square cores in pull-off instead of circular cores are easier to execute in light-compact renders; 2) samples in capillary absorption and drying test did not have their lateral faces waterproofed paint; 3) the surface was not smoothened with the carborudum piece before the pendulum hammer test. Finally, the procedure of hydrostatic weighing (Archimedes principle) includes the saturation process with high pressure until reached constant mass (Flores-Colen et al., 2006).

Also, reliability indicators were applied to allow better interpretation of results (from different techniques) and to choose the more reliable parameters in each case study. Therefore, a global reliability indicator was determined through the average of three partial reliability indicators (Flores-Colen, 2009), namely: 1) indicator related to the uncertainty of the based criteria established in lab testing; 2) indicator related to the uncertainty of the techniques of assessment; and 3) indicator related to the uncertainty of the results, in terms of the number of the tests and their precision.

The results also showed that in-service inspections have several limitations: the techniques are applied only to accessible areas of façade; the recommended number of tests cannot be ruled only by the area of the façade; and the majority of these techniques affect the aesthetic of the render, even the techniques usually called non-destructive (e.g. ultra-sounds or Karsten tubes).

In this context, the methodology proposes the number of random areas to be tested, as a function of: inspection type (normal or detailed inspection); number of lots (the façade is divided in a regular grid, with a minimum of 5 divisions per side). The conformity of each parameter is checked when the number of non-conformities are below the limit proposed in standards (ISO 2859-1 (1999) and ISO 3951 (2005)), that is a function of the type of inspection and the pre-established quality limit (AQL represents the non-conformity accepted by the intervenients in the decision process; two values are proposed 4 and 15%); for example: the number of non-conformities (in each parameter and area analyzed) is 1 for a AQL of 4% and 13 to 19 tests results in a normal inspection; for the same AQL and number tests, but in a detailed inspection, the number of non-conformities is nil.

3.5.5 CONCLUSIONS

It is concluded that there is a potential to follow this methodology (with expedient techniques instead of more advanced techniques that can increase costs and time consuming of inspections) of rendering condition assessment, even though its reliability can only be acquired through wider and longer experimental campaigns. The actual performance in-situ during early age of rendering façade is yet to be fully understood (an important step to maintenance planning), therefore, more studies and further research should be conducted in sound and damaged samples. However, in-situ results showed that the behaviour of renders applied in in-use conditions is usually different from the one expected based on lab experiments. Two main factors can justify this situation: the influence of the execution activities of renders (techniques for application or amount of mixing water) and existing degradation of applied render (some anomalies can affect more one parameter than others: e.g. pulverulence due to problems on product formulation led to a higher resistance to drying, but it did not affect significantly apparent porosity).

In conclusion, condition assessment based on visual is insufficient to characterize the behaviour in-use conditions, especially when the anomalies are less visible. The majority of the proposed parameters and criteria of assessment can give indirect indicators to monitor the behaviour of rendering façade (current area and also interfaces, in terms of degradation and also in-service performance); can reduce the subjectivity of visual assessment and can improve the correlations between natural and accelerate ageing tests.

It is obvious that this type of criteria allows a better knowledge of in-service performance, degradation mechanisms and pathology effects. The limitations of this analysis were related to the uncertainty of each parameter and assessment technique. The combination of several techniques and the choice of random test areas can improve the reliability of the diagnosis of the whole façade. In spite of these conclusions, further research in more case studies is needed to improve the proposed criteria of assessment and to create other parameters (with more reliable techniques), especially the ones related with the stresses induced by shrinkage, deformation capacity and hydrothermal behaviour.

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3.6 QUALITY CONTROL IN DESTRUCTIVE SURVEYS

(Josifas Parasonis)

3.6.1 INTRODUCTION

The improvement of the calculation and designing methods of load-bearing structures allows for better reliability, economy of materials, and improvement of the technology of used in production and quality control. The present time is characterized as lagging behind in terms of production technology and quality control, considering the level of the calculation methods. Designing structures by using state-of-the-art calculation methods is often not related to the production technology and, particularly, to the methods of quality control. The analysis of normative acts for designing structures, their production and quality control, reveals that sometimes their mutual consistency is insufficient. The current level of development of the calculation methods of load-bearing structures, according to the limit state design and the applied reliability theory, are the actual pre-conditions for the improvement of quality control [1]. The possibility to perform the quality control of these structures during production and usage, by collecting information according to separate parameters, which affect the structures' reliability, has proven a reality. This circumstance promotes the development of non-destructive quality control methods. The information obtained through these methods is also very useful when performing the quality control of structures by loading them with an external load, also known as destructive testing methods. Actually, they are destructive only when the test loads lead to the destruction of the structures. This happens most often when scientific investigation tests of newly designed experimental structures, or production quality tests of mass-produced prefabricated structures, are periodically carried out.

3.6.2 SIGNIFICANCE OF THE DESTRUCTIVE QUALITY CONTROL METHODS

The prerequisites of the design of load-bearing structures are the reason for a certain nonconformity between their real behaviour, and that assumed at the design stage. Thus, the construction methods are applied based on the results of experimental researches, allowing assessing and ensuring the required reliability of the structures. The knowledge of the real behaviour of the structure determines its economy and reliability. However, bringing it closer to that assumed at the design stage, depends not only on the prerequisites applied in calculations of statics, but also on other factors: the physical and mechanical characteristics of materials, the quality of the production and execution works and the conditions of usage. The calculation of structures according to the limit state design allows assessing the effect of separate factors on the reliability of structures. However, the lack of sufficient statistical data about the variation of such factors prevents their reliable assessment at the design stage. In addition, resulting from the condition of reliability, the absence of such data prevents from selecting the values of permissible deviations for these parameters, performing efficient quality control and regulating the manufacturing conditions of the structures.

Quality control is most often oriented towards the execution of the operational control. The determination of separate parameters of the structure through non-destructive quality control methods, not always allows judging upon the reliability of structures without a verifying calculation. At the moment, there is not complete clarity in interpreting the results of this type of methods, while assessing the reliability of structures; though, partially, these issues have already been discussed in several normative documents. Today, the determination of permissible deviations for separate parameters of structures, which determine their reliability, is not sufficiently related to the technology of production and execution works of the structures [2], or to the conditions of usage. For the meantime, only the ultimate strengths of the structural materials are controlled and assessed according to their real variation.

Due to the aforementioned, the integrated assessment of the quality of load-bearing structures is available in two ways:

- By applying the load (gradually, in stages) to the structure, until reaching the reference value of the load or up to the breaking). During the test, the calculated and fixed parameters (internal forces, stresses, strains and displacements) are compared. During this quality control, the integral quality control of the structure takes place. The results obtained during the test allow determining the ultimate strength, rigidity and cracking resistance of the tested structure;

- By determining separate parameters (physical and mechanical characteristics of materials, geometrical dimensions of common and separate cross-sections, protective concrete layers of the reinforcement, stresses of the steel, etc.) of the structure, using non-destructive methods affecting the quality of the structure. The values of these parameters are compared to the design and normative values; if required, the fixed values of the parameters are confirmed by the verifying calculation of the structure.

For quite a long period time the first method was the only one, though it was very complex and presented a few flaws. Naturally, when applying the load to the structure, it is economically unjustifiable and practically impossible to carry out frequent tests of a large amount of structures. Thus, for example, to analyse the quality of mass-produced prefabricated structures, ,it is necessary to decide upon the quality of a large amount of structures based on the test of separate products (samples of the batch - according to the requirements of certain normative documents; in case of mass-produced structures, their selection for destructive tests is carried out as follows: 1% of structures from every batch or 2 structures, when the batch contains less than 200 structures). This means that the test results of two structures actually provide the evaluation basis for the remaining 198 structural members of the batch. Furthermore, in the case under consideration, such quality control (test up to the breaking load) requires additional structures to compensate for the ones tested during the production process.

On the other hand, testing structures by applying loads allows the ultimate and integral assessment of the quality of structures: for example, carrying out such tests on separate structures or their fragments in real construction (in this case, naturally, the load cannot exceed the design value as the tested structure cannot fail during the test), provides the possibility to check the quality of the design, production and (in case of the fragment test) the construction and execution works.

The second (non-destructive) quality control method of load-bearing structures has been intensively developed during the last 30 years. It is promoted by the widespread usage of factory built structures, especially prefabricated concrete ones, and by the development of the reliability theory of structures. Also, the determination of separate parameters of the structure by non-destructive methods allows not only the assessment of its quality and reliability, but also the compilation of the adequate statistics of the parameters required to develop the applied reliability theory [1, 2].

Both methods of quality control (by applying the load to the structure or by determining its separate quality parameters by non-destructive methods) are appropriate. It is worth noting that the second method is also important in executing the operational control of the production of structures.

Objectives of the tests of load-bearing structures by applying the load are as follows [3]:

- Scientific, when a new structural solution is designed or when new materials are to be applied to the established structural solution. Then, the objective of the test is to check the viability and the reliability of the used calculation methodology and design tools;
- Industrial, when samples of the batches of mass-produced structures are periodically tested, according to the test results of which it is decided upon the total (residual) batch. In this case, the objective of the tests is to check whether the production technology of structures is accurate and whether it ensures the design parameters of the structure (ultimate strength, rigidity, cracking resistance, etc.);
- Experimental or pre-design, when the test of the separate structure or the fragment of the structure is carried out in a real construction. The first are required when there are doubts about the accomplished works or the quality of the used materials, as well as about the occurrence of different damage in the structure during the execution of building works or while maintaining the structure. The second (pre-design) tests are sometimes carried out during the preparation, to design the project for the reconstruction works of the construction.

The aforementioned shows that in order to achieve the stated objectives there cannot be a unanimous programme for the test of structures by applying external loads. Due to the significance of the objectives and the diversity and complexity of the test performance, the improvement of load applying tests is relevant.

The most complex destructive test methods are the scientific ones. Special experimental samples are produced to carry out such tests, by a thorough record of the data of every production stage, required for the preparation of the test programme (for the calculation of reference values of the parameters), and later on to assess the test results appropriately. The test is carried out with a number of different tools arranged in certain places of the structure for recording the ultimate strengths and displacements of separate components, and the deflection of the whole structure. The load is applied in stages, with increments not exceeding 0.05-0.1 of the limit (breaking) load value. The analysis of the results obtained during the test allows deciding upon the validity of calculation and design methods used at the design stage. Naturally, the way of applying the load to the tested structure has to be such that at certain stages, when certain values are achieved in the course of the test (close to the design values), effects would appear on the components of the structural member, because of the influence of characteristic and design loads' values. Moreover, this rule is valid for the preparation of the programmes of all the aforementioned destructive methods.

Requirements for the programme of experimental and pre-design tests of structures are similar to the earlier discussed scientific tests; however, in this case, there is notably less information about the production parameters of the tested structures, only a part of which is possible to determine by using non-destructive methods. As it was mentioned before, the maximum load of these tests cannot exceed the design value. The analysis of the obtained test results allows deciding upon the sufficiency of the bearing capacity (in a broad sense) of the structural member and of its assemblies, the danger of existing damages, the quality of building and execution works and the necessity of strengthening the construction.

For industrial tests, it is proposed to select visually the simplest samples of the batch. Naturally, they cannot be already known at the stage of their production, that is, they cannot be specially produced, as in the event of scientific tests. As it was mentioned above, the main goal of these tests is to check whether the established production technology of the structures ensures its production and the design characteristics of the bearing capacity.

Experimental, pre-design and industrial tests of the load-bearing structures are carried out with the minimum amount of the required tools.

3.6.3 ASSESSMENT OF THE RESULTS OF THE DESTRUCTIVE QUALITY CONTROL METHODS

The fundamental criteria for the assessment of destructive tests are the comparisons between parameters recorded (measured) during the test and the calculated (reference quantity) ones [3]. The main parameters to be recorded are stresses, strains and displacements of the most loaded elements (sections) of the structure and, while testing up to the breaking load, the value of the maximum load and the nature of the failure.

While analysing the test results of the structure's rigidity tests, it is important that the value of the maximum measured displacements does not exceed the reference value. If, while submitting the tested structure to the characteristic load, its maximum deflection does not stop increasing, it is a serious indication that the rigidity of the tested structure is insufficient. The carrying out of the rigidity tests shows that it is advisable to keep the structures subject to the characteristic load value (that being, the reference value deducted of the weight of structure, when the test is carried out in a vertical position) for no less than 12 hours for reinforced concrete structures, and 24 hours in the case of wooden structures. While assessing the rigidity of the tested structure, it is also important to measure the value of the residual deflection, after unloading the structural member. With reference to the practice of these tests, the, the value of the residual deflection is considered acceptable when, after unloading, it does not exceed the phase of 1/5000 and, after reloading and unloading, it does not exceed 0.05 of elastic deflection. The residual deflection for structures of reinforced concrete without the pre-tension reinforcement cannot exceed 0.33 of its elastic part and for wooden structures – 0.2 of elastic deflection.

The assessment of test results of the cracking resistance of reinforced concrete structures, is carried out by comparing the calculated and measured crack forces (action - effects), and the calculated and measured crack widths. While calculating reference quantity values, it is important not to forget that we have to operate only with their short-term values.

The assessment of test results regarding the ultimate strength is a more complex task, especially, when not testing up to the breaking load. In this case, the ultimate strength of the structure is assessed indirectly, because the value of the breaking load and the nature of the failure stay unknown. The ultimate strength of the structure is determined directly only when the structure is tested up to destruction. It is necessary to know that this assessment differs and depends on the objective of the test: if the aim is to check the validity and reliability of the used calculation methodology and design tools, in other words to evaluate the pre-suppositions of the design, then the actual destruction load is compared with the calculated load. A slightly different approach is applied in case of mass-produced structures because, as it was mentioned above, the objective of the test is to check the production quality. Then, the criterion for the ultimate strength of the batch is considered adequate when the actual destruction load of all tested structural members is no less than the reference quantity one.

The practice of the methods applied to mass-produced structures, shows that in order to provide a reliable assessment of the ultimate strength of the structure, it is necessary to know the nature of its destruction. With reference to, for example, the quality control practice of reinforced concrete structures, there are three types of nature of destruction:

- The yield of the tensile reinforcement up to the breaking of the compressed concrete;
- The break of the tensile reinforcement;
- The breaking of the compressed concrete, before the event of the yield of the tensile reinforcement or the breaking of the flexural member along the inclined cross-section.

The reference value of the breaking load of tested structures, for the assessment of the ultimate strength, may be calculated by multiplying the design (calculated) value (containing the weight of the structure) by the factor (C), whose value depends on the number of samples, the nature of predictive destruction and the probability of the desired reliability. The types of nature of the destruction show that the first one is referable to plastic (slow destruction) and the other two, to a brittle (sudden destruction). It may be concluded from the abovementioned that the second and third types of destruction are more dangerous. Thus, upon the occurrence of such danger,,a greater value of the factor (C) has to be adopted. With reference to the basic provisions of the normative documents regarding the design of load-bearing structures, according to the limit state [4], for the determination of characteristic and calculated (design) values of materials' parameters, it is important to be aware that the nature of the ultimate strength of all materials, is statistical and its variation is standardized in adequate design norms..In other words, the variation of the ultimate strength of concrete, metal, wood or masonry and, partially factors of reliability are standardized and known. After the decision is made on the reliability of the desired result, it is easy to calculate the minimum value of the reference factor (C) or of the reference value of the structure's breaking load [5], which if reached during the test, allow to conclude with accepted probability, that the ultimate strength of the tested structure, and of the rest of the batch, is sufficient.. Depending on the predicted, or actual nature of the destruction, and on the number of tested structures (for example, for prefabricated structures testing more than 2 members but no less than 4 members), the reference value of the C factor is suffers alterations. For the first type of abovementioned destruction, the reduction is of 15%, whereas upon the occurrence of the second and third types of destruction the C factor is increased by 15 %. The practice of the test on mass-produced load-bearing structures shows that the reference value of the factor (C), for reinforced (heavy) concrete structures, varies in the range of 1.2-1.6 and for steel structures – in the range of 1.1-1.3.

It is necessary to note that it is possible to assess whether the structure is correctly designed by comparing the values of strains, displacements, crack widths and breaking loads measured during the test with the calculated (reference) ones. The parameters measured during the test and calculated on the base of the test results, may differ:

- According to the ultimate strength - + 10%, - 5%;
- According to cracking resistance and rigidity - 15%.

Since it is impossible to have many samples while carrying out quality control by destructives methods, it is important to know the reliability of this type of assessment. From our calculations, the probability of the rejected products in a batch of mass-produced reinforced concrete structures, positively assessed according to the ultimate strength, is quite high (24.5 %). The detailed assessment results of the ultimate strength, rigidity and cracking resistance, is provided [6] by applying a normal distribution, considering the confidence probability of the assessment of 0.995 to be acceptable, after the breaking of the compressed concrete, up to before the yield of the tensile reinforcement. That is, when the number of tested structures to determine the nature of their sudden destruction is 4, and, when the standardized variation of the suppression strength of heavy concrete is 13.5%.

When the samples' destruction is of plastic nature, and, the variation of the yield range of the reinforcement is 6.7%, as mentioned earlier, the probability of the rejected product in the batch for other output data is notably smaller and accounts for 8.2%. In order to achieve such a level of risk, in the case of the third type of destruction, the approximate number of structures to be tested from every batch, should be 14 units.

The assessments of the test results of mass-produced structures carried out by destructive methods show that, in order to achieve a high level of reliability, a notable increase in the number of samples of every batch is necessary. Naturally, this is not acceptable. Evidently, the improvement of the quality control of mass-produced structures by increasing the application of non-destructive methods, while carrying out operational quality control during the production stage, is a meaningful task. The testing of structures by applying loads is necessary in order to achieve scientific, and sometimes experimental and pre-design objectives.

3.6.4 REFERENCES

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3.7 SURVEY INFORMATION SHEETS

(Inês Flores Colen)

In order to provide immediate, easy access to the most relevant Surveys, we find it crucial to present the information by means of a user-friendly interface. The Surveys Information Sheets that follow are but a small sample of the currently applied techniques for coating walls, but serve nonetheless, as a starting point for future developments. The sample is comprised by the following surveys:

- In situ adherence through Pull-off test (pag. 79), from the authors Inês Flores-Colen , Jorge de Brito e Fernando Branco;
- Impact resistance through Martinet Baronnie (pag. 80), from the authors Inês Flores-Colen, Jorge de Brito e Vasco Peixoto de Freitas;
- Bulk density and open porosity through on-site samples testing (pag. 81), from the authors Inês Flores-Colen, Jorge de Brito e Vasco Peixoto de Freitas;
- Ultrasound technique (pag. 82), from the authors Jorge Galvão, Inês Flores-Colen e Jorge de Brito;
- Rebound hammer technique (pag. 83), from the authors Jorge Galvão, Inês Flores-Colen e Jorge de Brito.

Coating walls - in situ adherence through pull-off test

DESCRIPTION OF THE SURVEY/TECHNIQUES

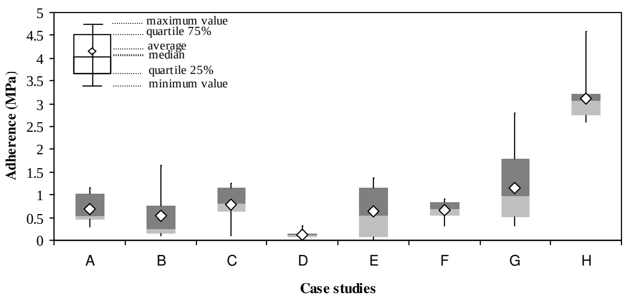
The pull-off test is a destructive technique that allows in situ evaluation of the resistance to tensile extraction (bond strength) of various coatings. In this information sheet the results of this technique in eight case studies (ceramic tiling, pre-dosed mortar, interior renders, gypsum plaster, waterproofing paint / mortar, and resin paint) are briefly discussed. The purpose is to evaluate the adequacy of the pull-off test for in situ estimation of coating materials.
The inspections performed included in general two distinct types of analyses. First, visual observation with a photo survey led to the selection of the adequate location for gluing the disks. After that, the experimental campaign was performed. Where total loss of adherence was detected the tests were performed in adjacent locations where the coatings were still adherent to the substrate. To arrive at this conclusion, the surfaces were tapped with a hammer and the resulting sound was qualitatively evaluated.
The data relative to each case study has been summarized in terms of: reason for testing, their location, and month of inspection, extension of the anomalies, and type of observation (visual with or without expedient percussion by a hammer). In five of the cases the study focus was on the degradation of the coatings and in the remaining three on quality control (evaluation of the mode of preparation of the substrate, evaluation of the different options of coating chosen by the designer, and evaluation of the coating's adherence after its application) according to normalized procedures .The external inspections occurred during April-October months, with dry weather conditions and environment with moderate temperature (18-24ºC) in three cases and with high temperature (30-35ºC) in other three.

PROCEDURE

This test aims at evaluating the adherence capacity of the coating to its substrate. The pull-off test is described in LNEC (Portuguese National Laboratory of Civil Engineering) test form FE Pa36 for wall coatings, European standard EN 10115-12 for rendering and plastering mortars and European standard EN 1348 for cementitious adhesives. RILEM recommends the same technique to evaluate the adherence between bricks and mortars, according to MR 21, and an in situ adaptation of the technique described in EN 10115-12, according to MDT.D.3. The pull-off test consists in extracting with a pull-off device a metallic piece (usually a disk) previously glued to the coating with an epoxy resin. In order to guarantee that the pulling-off occurs only under the disk a groove is previously cut in its perimeter deeper than the coating's thickness. The device measures the force necessary to extract the disk. The ratio between this force and the disk transverse section corresponds to the pulling-off resistance, i.e. the maximum tension that can be applied to the coating. Rupture may occur by loss of adherence of the disk (faulty gluing), in the interface between the coating and the substrate (adhesive rupture - type a), rupture of the coating material (cohesive rupture of the coating - type b) or of the substrate (cohesive rupture of the substrate - type c). Frequently the rupture does not conform to any of the types mentioned, resulting from a combination of two or more of them. The tension that causes the rupture in the interface coating / substrate (adhesive rupture) is called yield stress. If the rupture is cohesive (types b and c) the value obtained is equivalent to a minimum of the adherence stress that can be used to determine the mean value of the pull-off resistance.

RESULTS

The results obtained for the eight case studies have shown a high scatter of test results with coefficients of variation (standard deviation / average * 100) above 32% in all cases. Since the average results may result distorted by individual extreme values, the box-plot diagram of below figure was prepared to facilitate the comparative analysis of the case studies, by indicating: the average and median of the results, the lower (25%) quartile, the upper (75%) quartile, the highest and lowest result. The results of the rupture modes (adhesive and cohesive) in each case, including the average values of each failure stress, percentage of each failure mode (a, b or c) and its location within the coating system were systemized. Every rupture that occurred in the epoxy glue (interface between the test piece and the surface of the coating system) was considered nil.

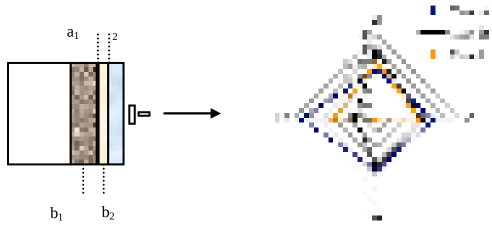


(Flores-Colen, et al., 2009)

INTERPRETATION

The results were discussed in terms of: i) results variability of pull-off tests; ii) average results of adherence in each coating system; iii) percentage and effective average of failure stress in interface of coating materials; iv) adherence extreme values (minimum) analysis in each coating system; v) in-situ observation of samples after testing; vi) degradation process in coating systems; vii) quality in control systems.

The eight case studies allowed the identification of the potential of in situ application of the pull-off technique for degradation cases of loss adherence / detachment and for quality. It was found that only in a few cases the analysis of the average values of the adherence tension by itself was enough to allow a diagnosis of the situation, due to the higher scatter of values and different types of rupture modes within the materials that make up the coating system (e.g. see figure below). The observation of samples (probing technique) was revealed as very important to justify minimum tension values. Finally, two ways for improving this technique can be proposed: conjunction with non-invasive techniques (acoustic tracing, thermography, Doppler interferometry) or systematically approach for pull-off technique.



KEYWORDS rendering wall, in situ adherence evaluation, failure stress, modes of rupture.
AUTHORS/INSTITUTIONS (p.e.) Prof. Inês Flores-Colen (IST); Prof. Jorge de Brito (IST); Prof. Fernando Branco (IST).

Coating walls – impact resistance through Martinet Baronnie

DESCRIPTION OF THE SURVEY/TECHNIQUES

The impact resistance of claddings and walls is assessed through three types of standard impacts: (1) impact of a soft body (heavy and big) capable of transmitting significant energy by impact (affecting the wall + render assembly) - e.g. contact of a moving shoulder); (2) hard body (light and small) capable of producing localized deterioration by impact, with no significant energy transmission to the construction element as a whole (background) - e.g. projection of small non-deformable objects such as stones; (3) soft body (small) that simulates impact actions of bodies with a hardness level between those of soft big bodies and hard bodies and produces an effect that is a combination of the previous two (e.g. the impact of a small area of the human body, like the knee, or the projection of small deformable bodies, like a football).
The performance levels in terms of impact resistance are classed according to the minimum energy that the surface withstands without degradation, and the damage acceptance criteria depend on the susceptibility of façade rendering to impacts, its accessibility to users / passers-by, the colour and texture of the surface, and the repair cost.
The Martinet Baronnie device has been used by several authors, both in laboratory and in situ, to evaluate the impact resistance of renders, under the following terms:

- Adequacy of plasters - values depending on the compartment, e.g.: spaces with collective use more than 2 m above the ground or surfaces less than 2 m above the ground;

- Comparison of several types of renders and plasters - lime and cement render; modern gypsum plaster; traditional gypsum plaster releasing 80% of water;

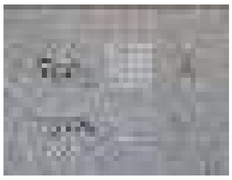
- Assessment of the degradation state of old lime mortars and definition of the type of intervention and adequacy (minimum strength) of new lime mortars; these criteria are only valid if analyzed simultaneously with the controlled penetration test.

PROCEDURE

The Martinet Baronnie device allows the evaluation of renders in terms of impact resistance to hard bodies (non-cutting and cutting), using two different tests (testing procedures of Portuguese National Laboratory of Civil Engineering -LNEC - FE Pa 25 and FE Pa 26): the sphere impact test and the cut-off impact test. It is recommended that this device is used to carry out 3 to 10 tests at different points on the surface, the number depending on the surface's homogeneity. This device can also provide abrasion, scratch and staining tests on rendered surfaces.

The sphere impact test, using the Martinet Baronnie device, consists on impacting a non-cutting hard body (a steel sphere of 50 mm diameter) that is equivalent to energy of 3 Joule. This test provides data on the deformability of the render. At the end of each test, the diameter of the notch (Ønotch) produced by the sphere impact is measured, with a special ruler with 0.1 mm precision. The cut-off impact test is used to evaluate both the resistance of the render to the impact of hard cutting bodies, and the cladding's cohesion, when subjected to impacts of cutting-edge objects. This test resorts to increasing energy levels (within a limited range of 6 Joule), using a metallic dented block with different masses (250, 500 and 1000 g), which produces a grid of 16 squares on the rendering surface. At the end of each test, the highest impact mass (Imass) that the coating withstands without scaling or detaching (checked on the square grid produced by the blocks is registered. Therefore, according to the existent procedures, the values of this indicator can be: 0, 250, 500 or 1000. Imass will be equal to 0 when render does not withstand all test masses, and equal to 250, 500 and 1000 when it shows good performance to mass 250 g, 500 g and 1000 g respectively. The surface is considered to have withstood the test if at least 3 of the 5 individual tests are successful. In this case a resistance index is attributed that corresponds to the value of Imass.





RESULTS

The Martinet Baronnie device was used to evaluate the impact resistance of rendering mortars in the laboratory (evaluation of small-scale brick and render models) and in situ (investigation on rendered walls). The results concerned two surface impact resistance parameters related to the render deformability and cohesion after impact: notch diameter produced in sphere impact test of 3 Joule (non-cutting hard bodies) and mass index, based on 55% undamaged squares, which the render withstands in a cut-off impact test (cutting hard bodies), within a limited range of impact energy of 6 Joule.

Lab tests shown that a decrease of the diameter of the notch (direct measure of less deformability and therefore greater impact resistance) for almost the renders corresponds to: i) an increase in the bulk density, compressive strength, adhesion strength, and dynamic modulus of elasticity; ii) a decrease in the apparent porosity (the more porous the materials are the lesser the impact energy to generate deformation). The mass index has shown a similar trend to the diameter of the notch (higher impact resistance leads to less deformability of the render to the cutting and no-cutting bodies and also to higher render cohesion). However its evaluation only allows a semi-quantitative perception of impact resistance. The in situ tests has shown: i) the impact resistance is satisfactory, notwithstanding the existing cracking; slightly higher impact resistance can be justified by the conditions of application of renders, e.g. mechanical projection;; 2) the excessively deep pulverulence is associated with a lower resistance ; crazing cracking, scaling areas and biological colonization may have contributed to the lower render surface cohesion and to the lower impact resistance to cutting bodies testing.

INTERPRETATION

After a literature review, it was concluded that this technique only evaluates serviceability impacts of hard bodies on façades with certain exposure classes, namely the ones that are subjected to in-service impacts of 3 or 6 Joule (e.g. fenced private areas, areas 1.5 or 2 m above the ground) or if there is maintenance on rendered façades (e.g. public area with no footpath or risk activities). The results of the laboratory experimental campaign have shown good correlations coefficients between impact resistance parameters and other characteristics reported in well-known standard and technical documents (bulk density and dynamic modulus of elasticity, according to the MERUC classification, and compressive strength according to EN 998-1.

Therefore, performance classes were proposed for external renders, based on laboratory experiments carried out on various compositions of mortars used in external renders. The on-site investigation included the analysis of 20 rendered walls with different types of mortars (pre-mixed and made on-site mortars), ages and anomalies. These results have shown that this technique can be applied to in situ evaluation of contemporary renders because it allows the comparison between in situ impact resistance parameters and the expected impact performance for each render (performance classes based on laboratory tests) and also the influence of existing degradation on surface impact resistance (anomalies associated with loss of performance, such as pulverulence). In fact, this technique can reduce the subjectivity of visual assessment and recommend the areas of render that need a detailed investigation in terms of mechanical in-service behavior.

KEYWORDS rendering wall, impact resistance evaluation, sphere impact test; cut-off test.
AUTHORS/INSTITUTIONS (p.e.) Prof. Inês Flores-Colen (IST); Prof. Jorge de Brito (IST); Prof. Vasco de Freitas (FEUP).

Rendering walls - Bulk density and open porosity through on-site samples testing

DESCRIPTION OF THE SURVEY/TECHNIQUES

Collecting samples under in-service conditions and analyzing them in the laboratory may complement the data acquired with other in-situ diagnosis techniques since it is possible to study the material actually applied and not the one produced in the lab (under controlled conditions very different from the real ones). Measuring given in-service parameters in small samples collected during inspections may provide relevant data within a performance evaluation methodology for rendered façades, especially when there are no in-situ tests to analyze certain in-service parameters (such as bulk density and open porosity). Even if it is possible to collect samples it is difficult to guarantee that they are representative since many samples would be required to ensure this. The parameters (bulk density and apparent or open porosity) were analyzed in small samples collected from models produced in the laboratory (first stage) and from façades of real buildings (second stage).
The bulk density of hardened mortar is defined as the ratio between the dry material's mass and its total volume (including that of open pores). This parameter is prescriptive for an adequate compacity of mortars in various uses and in-service conditions. According to EN 998-1, it must be declared by the manufacturers, with a minimum value of 1300 kg/m3 for general use pre-mixed mortars. Furthermore, according to NP EN 1745, the bulk density of mortars may be as much as 2000 kg/m3, even though it must be limited in certain-situations, such as in mechanically weaker or more absorbing backgrounds and also when the surface is finished with a trowel.

• Open porosity concerns voids that inter-communicate to allow the circulation of fluids within the mortar (the material is more or less permeable depending on the size and geometry of the pores). Several researchers have reported current values for various types of mortar, classified pore size and established methods to determine this parameter. The values of porosity reported in the technical literature for cementitious mortars vary but they are lower than those for lime mortars or cement-lime mortars. According to Begonha (2011), open porosity of cementitious mortars lies between 20% and 25%.

PROCEDURE

Bulk density (MapPG) can be determined by two methods. With geometric measurement, bulk density is equal to the ratio between sample mass and its volume determined geometrically (e.g. with a paquimeter). In hydrostatic weighing, saturated samples are immersed and weighed and the following equation is used to determine the bulk density (MapPA).

$$M_{ap}^{PA}(kg/m^3) = \frac{M_1}{M_3 - M_2} * 10^3$$

Where: M1 = dry sample mass (g); M2 = sample mass (g); M3 = saturated sample mass (g), maximum value until constant mass.

Hydrostatic weighing is better for samples of every size and it is the only adequate method for irregularly shaped samples.

Open porosity is measured by microscopy or intrusion techniques. The most current ones are water immersion (sub-pressure or pressure) or mercury porosimetry. Only the latter also allows data collection on the porosimetric distribution (pore size and shape). The hydrostatic or underwater weighing method cited above for bulk density, also allows the determination of open porosity, using the following equation.

$$P_{ap}(\%) = \frac{M_3 - M_1}{M_3 - M_2} * 100$$

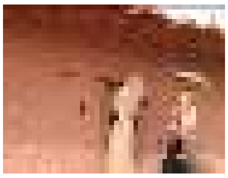
According to Navarro (2003), this method was established for stone by Hirschwald (1912), standardized by RILEM/PEM25 (1980), and later on extrapolated to other materials such as mortars and ceramics (ASTM, 2006).



RESULTS

A laboratory campaign was initially implemented to study the relationship between these parameters and the mortars' in-service performance characteristics and to establish reference parameters. This experimental campaign consisted of producing standard samples (3 samples for each property to be studied measuring 4 x 4 x 16 cm3 or 2.5 x 2.5 x 28.5 cm3 in the dynamic elastic modulus determination), and also of 9 small-scale models (1.5 cm of render + brick substrate, with dimensions of 49 x 19 cm2

In in-situ campaign, several samples collected from 15 rendered walls from 7 case studies were analyzed (2 to 4 samples in each wall). Samples were collected in two ways: directly from the wall or from cores yielded by pull-off tests. In the second situation, the cores were subjected to heat to remove the metal piece used for the test. Finally, the same techniques of assessment were performed in the laboratory on samples collected on-site, namely geometric measurement for bulk density assessment, and hydrostatic weighing for both bulk density and open porosity assessments. The rendered walls analyzed on-site provided several mortars evaluation; the age of renders from 1 to 40 years, and the anomalies found were similarly varied: micro-cracking; thin cracking and superficial to medium pulverulence; stains.



INTERPRETATION

From the experimental study carried out on samples collected from brick and mortar models made in the laboratory (first stage) and from façades in real in-service conditions (second stage) it is concluded that the hydrostatic weighing technique for small samples is simple to execute and provides relevant data for evaluating in-service performance through the determination of bulk density and open porosity of the mortars applied. These parameters characterize the expected in-service behavior, particularly when the type of render is unknown and/or when less intrusive in-situ test techniques are not available.
It was in fact possible to confirm the relationship between the two parameters under analysis, which indicates the connection between the global void volume and the compacity of hardened mortars and also their relationship with other physical parameters relevant to the mechanical and water-related behavior of applied renders.
It was also confirmed that the method of determination using a geometric measurement is not the most suitable one for in-situ evaluation since the results may be significantly influenced by sample irregularity (especially in the made-on-site mortars).
Finally, it is concluded that more experimental campaigns are needed to calibrate the procedures of the hydrostatic weighing technique. It is also important to study the influence of in-service factors in greater detail using samples from real applications, with an emphasis on the renders' application conditions and on existing degradation (types of anomalies).

KEYWORDS rendering wall, bulk density, open porosity, samples testing.
AUTHORS/INSTITUTIONS (p.e.) Prof. Inês Flores-Colen (IST); Prof. Jorge de Brito (IST); Prof. Vasco de Freitas (FEUP).

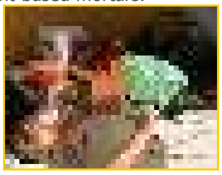
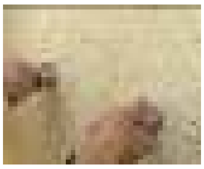
Coatings walls - Ultrasound technique

DESCRIPTION OF THE SURVEY/TECHNIQUES

The in-service evaluation of performance can be carried out in several ways. In most cases, a visual inspection is enough to detect pathological phenomena affecting the rendering because of it is evident and visible. However, this can produce data that is dubious or difficult to interpret. It is also affected by the education and experience of the technician carrying out the inspection, as well as the accessibility of the area being inspected. Furthermore, most problems affecting performance are often not visible, which means that they need to be measured. The use of auxiliary diagnosis techniques reduces the subjectivity of visual inspections, making it easier to obtain a more reliable evaluation. For these reasons, the use of those auxiliary techniques, in particular in-situ techniques, has proved increasingly beneficial in characterizing in-service performance, as a complement to visual inspection.

Ultrasound testing works by finding out how fast an ultrasonic impulse travels between two points, with a view to obtaining information about the characteristics of the elements being tested. It is a test with low destruction level and that also has the advantage of being quick and easy to perform.

The normal use of ultrasound testing is to evaluate the characteristics and properties of concrete. In the particular case of wall rendering, it shows the state of degradation of the elements tested, since discontinuities such as cavities and cracks affect the speed at which waves are transmitted. Materials in poor condition or with weaker cohesion register lower speeds than compact or less degraded materials. Because of this, ultrasound testing is used to diagnose anomalies, allowing potentially deteriorating areas (cracks, detachments, cohesion loss) to be located, and also in improving identification of deterioration and performance in façade rendering made from cement-based mortars.

PROCEDURE

Ultrasound testing was carried out in accordance with standard EN 12504-4 for concrete, with due adaptations. Equipment directly measuring transition time was used, employing transducers with a frequency of 54 kHz and a diameter of 5 cm.

The testing procedure began with the calibration of the measuring device, using the device's calibration bar, to a known transition time (26.2 μs). Measurements were taken using the indirect method, concentrating on areas with no apparent degradation. Vaseline or toothpaste was used to ensure contact between the transducers and the rendering.

The adopted method was to analyze 400 mm paths divided into 100 mm fractions, although in some cases 350 mm paths were analyzed, divided into 70 mm fractions, in order to obtain the results. The apparent pulse velocity was calculated using the following equation:

$$V_{ap} = \frac{d}{t}$$

In which:

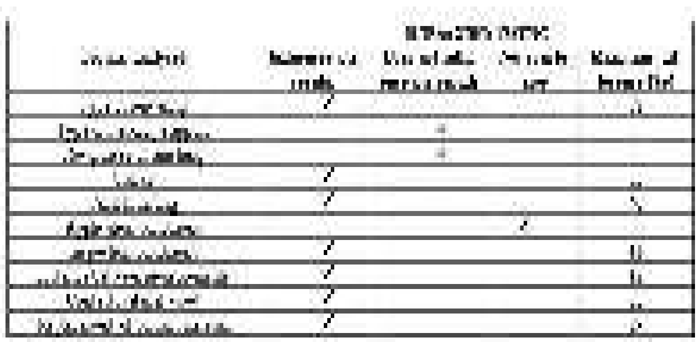
Vap - Apparent ultrasound pulse velocity (km/s);

d - Distance between the transducers along the path (mm);

t - Transition time (μs).

RESULTS

Two series of experiments were carried out at natural ageing stations and traditional and non-traditional coatings were analyzed. The first station was built at the end of the 1970s and since then it has been used in several studies on rendering mortar, thus allowing service performance to be studied. The station has a huge variety of applied renderings, ranging from thirty-year old traditional rendering to pre-mixed renderings using recent formulations. The prototype walls are mostly built from brick masonry to a thickness of 20 cm and ceramic tiles protect the upper sections. The second ageing station was built at the beginning of 2004 with the aim of monitoring the performance of pre-mixed products over time. Due to the large number of situations analyzed, it was possible to carry out an analysis of the precision of this technique, as a function of various parameters.



INTERPRETATION

The precision of this technique in relation to several parameters was studied, with the aim of identifying which parameters are influential and how this influence is shown in the results, so that they can be taken into consideration in future analyses. On the basis of all the factors analyzed, it can be concluded that the type of rendering, the existence of paint finishing layer and the inspection conditions influence the results. In addition, factors inherent to the technique itself also exert an influence, as well as the distance between measurements, the contact material used and its replacement. Out of all the factors mentioned, the type of rendering, the existence of paint finishing and the presence of cracks in the rendering were identified as the factors, which had the greatest influence.
The maximum differences analyzed were between 30% and 50%. However, other parameters also had an important influence, such as the contact material and its replacement, which registered differences between 20% and 30%. Finally, factors such as the inspection conditions and the distance between measurements had a lesser influence, of about 10%. According to the cases analyzed, certain factors such as the support material and the roughness of the finishing do not have significant influence on the results of ultrasound testing. In conclusion, the analysis of application conditions, especially the time of the year when the rendering was applied, is not conclusive, particularly given the number of cases available for analysis.
Despite these influencing factors the technique is useful for evaluating performance, as it allows for distinctions to be made between different materials and in-service conditions because it is particularly sensitive to different mechanical characteristics over time.

KEYWORDS rendering wall, ultrasound technique; indirect method; in-situ testing.
AUTHORS/INSTITUTIONS (p.e.) Msc Jorge Galvão (IST); Prof. Inês Flores-Colen (IST); Prof. Jorge de Brito (IST).

Coatings walls - Rebound hammer technique

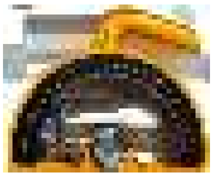
DESCRIPTION OF THE SURVEY/TECHNIQUES

The evaluation of how a render performs over time is a complex activity, not only due to the multiple factors concerning its exposition, but also to the difficulty in assessing the in-service behavior. According to this, the use of in-situ tests is very important because it gives the possibility to obtain the information about in-service performance of renders in real conditions.

Testing with a pendulum hammer is based on the rebound method, in which the reflection of an elastic mass launched against a surface depends on the surface hardness of the material under analysis. The result is shown on the sclerometric index as the rebound number, which is arbitrary as it depends on the mass and the energy stored by the device's spring. The softer the material, the greater the energy absorbed and the smaller the rebound.

The pendulum hammer is a device used in conjunction with other destructive or non-destructive tests mainly to calculate the resistance of a material from its surface hardness or to compare the quality of materials. It is quick to use and has been employed to test concrete and, more recently, in the in-situ characterization of walls and renders. In the latter case, it was used to evaluate the quality of the adherence of the rendering, as well as its homogeneity and uniformity.

Pendulum hammer testing is useful in characterizing degradation and in determining the mechanical performance of rendering. Also it allows mapping areas of poor performance (associated to the presence of moisture or lack of adherence).

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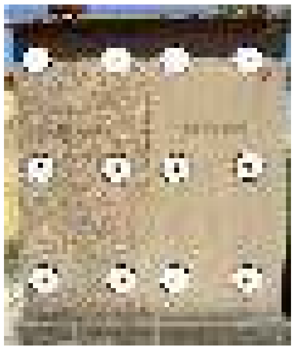
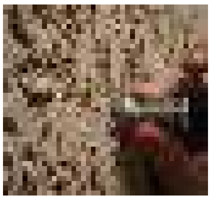
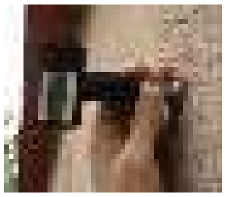
PROCEDURE

Pendulum hammer testing was carried out in accordance with standard NP EN 12504-2 for concrete, with due adaptations. The testing directly measured rebound values, with 6 to 9 measurements taken per wall. Contrary to established procedures for concrete, surfaces were not polished, as this has a significant aesthetic effect on the rendering (changing the color and texture of the product), and therefore the roughness of the render surface was also analyzed (high roughness, on the left of the following pictures and low roughness on the right roughness on the right).

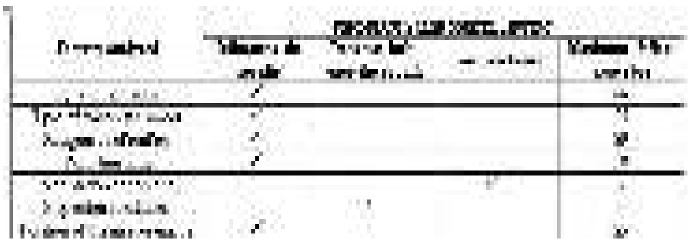


RESULTS

Two series of experiments were carried out at two natural ageing stations and traditional and non-traditional coatings were analyzed. The first station was built at the end of the 1970s. This station has a huge variety of renderings applied, ranging from thirty-year old traditional rendering to pre-mixed renderings using recent formulations. The prototype walls are mostly built from brick masonry to a thickness of 20 cm and ceramic tiles protect the upper sections. The rendering is applied on this support, and whilst traditional renderings are usually applied in 2 layers, with a total thickness of 2.5 cm, pre-mixed renderings are normally applied using a single-layer system 2 cm thick. These products are usually applied by technicians who have experience in application, so they can reproduce the methods used on-site as faithfully as possible.

The second ageing station was built at the beginning of 2004 with the aim of monitoring the performance of pre-mixed products over time. Due to the large number of situations analyzed, it was possible to carry out an analysis of the precision of this technique, as a function of various parameters. The prototype walls consist of a masonry support made from 7 cm thick bricks protected on top by ceramic roof tiles, onto which the rendering was applied to a thickness of around 2 cm.



INTERPRETATION

The precision of this technique in relation to several parameters was studied, with the aim of identifying which parameters are influential and how this influence is shown in the results, so that they can be taken into consideration in future analyses. Pendulum rebound hammer testing appears to be less precise in terms of the number of factors involved. The results showed that most of the parameters tested affect the results, including the type of rendering, support, the roughness of finishing, the existence of painting and the number of measurements made in each location.

The type of rendering and the existence of a paint finishing were the factors with the greatest influence on the results of pendulum rebound testing, with values from 45% to 60%. According to this analysis, the inspection conditions do not significantly influence the results.

Based on the precision analysis, it can be concluded that these factors must be controlled as far as possible during testing and must be taken into account in the analyses of the results.

The results also showed that the pendulum hammer can be used in the in-service evaluation of mechanical performance. However, the study also proved that this analysis is not always straightforward, and that it is advantageous to cross-reference the results of this technique with those of the ultrasound technique in order to clarify the more ambiguous situations. These techniques can be considered complementary and their combined use is thus advisable.

KEYWORDS rendering wall, rebound hammer technique; roughness; mechanical properties; in-situ testing.

AUTHORS/INSTITUTIONS (p.e.) MSc Jorge Galvão (IST); Prof. Inês Flores-Colen (IST); Prof. Jorge de Brito (IST).

3.8 DIAGNOSTIC SYSTEM FOR NON-DESTRUCTIVE SURVEYS OF BUILDING CONSTRUCTIONS

(Attila Koppány)

3.8.1 INTRODUCTION

It is important, that people in architecture science give a useful guide – especially concerning questions raised by new trends of the changing, transforming building activities and construction development – to the profession practice. Seeing that in the aspect of adequacy the appearance of new constructions and building materials always raises new problems to be solved, and the experts in practice busy with the daily tasks of the profession 'according to Möller (1945) cannot always pay enough attention to them'.

The efficient diagnostic activity as it has been explained before plays a very important part in the formation of maintenance costs and elimination of damage. It has a just as important part in the preparation of a decision, as having a clear picture of the technological conditions of buildings or group of buildings can be of service at the preparation before making financial decisions of great significance.

Our research group in Győr had a twenty years long activity in the field of building pathology. Building pathology 'according to Trotman (2001)"is essentially concerned with the methodology of investigating defects and failures in buildings (CIB 1993). There is difficulty in defining what is meant by a defect and what qualifies as a failure. CIB Working Commission W086 discussed definitions at length and a list in their report illustrates the process of 'birth and life" of a building defect. Many problems will occur because human activities (titled "errors or omissions") fall well short of planned or anticipated performance".

We collected a big amount of defects and failures in Hungary and we needed an effective method to evaluation of data. We had a very useful issue about data collection and evaluation from CIB W086. As a member of this Working Commission the author has taken part in the discussion about the diagnostic methods and tools and about the creating of Building Pathology Forum for website.

3.8.2 DIAGNOSTIC SYSTEMS

A faulty diagnosis can lead to incorrect decisions causing financial loss. The research group of the Széchenyi István University (Győr) worked out such a comprehensive diagnostic system which contains a common inspection method 'according to Molnárka [2000] for the vast majority of constructional components (for traditional and actually used constructions in Hungary), and can be used for computer data registration and analysis.

Before our developing work we studied many of diagnostic and evaluation systems. Most of them there were useful for energy evaluation in the field of apartment buildings for example EPIQR (see figure 39). In the frame of JOULE programme European Commission project EPIQR (energy performance, indoor air quality, retrofit), apartment buildings were investigated with a tool EPIQR. This program has been developed as a result of two-year research project, involving seven European research institutions (BRE, CSTB, IBP, SBI, TNO, NOA, EPFL).

The EPIQR survey has been implemented in multimedia software. It assesses the apartment building on 50 elements. Each element is graded on four-point scale from good to poor condition. The software displays visual and descriptive stages of degradation for each element. During the condition survey information is gathered on building characteristics and on the energy consumption of the building by the means of a walk through energy audit, in conjunction with fuel bills.

The program performs heating and cooling load calculations, and assesses various energy conservation techniques. EPIQR program has been developed first of all for evaluation of apartment building, but in Hungary it was applied for the evaluation of school and polyclinic buildings too.

The EPIQR computer programme is originally a stand - alone programme with its own user interface. Wittchen and Aggerholms (2000) found that…"In EPIQR some input parameters have been fixed to ensure that user only has to supply simple input data to carry out a heating requirement calculation".

Our developing work prepare for MÁV (Hungarian State Railways), who has about 10 000 buildings, and most of them are industrial or commercial buildings. The first phase of our work was to create a construction registration system and the next task was to develop the visualisation of the results to make useful sign for the screen of user's.

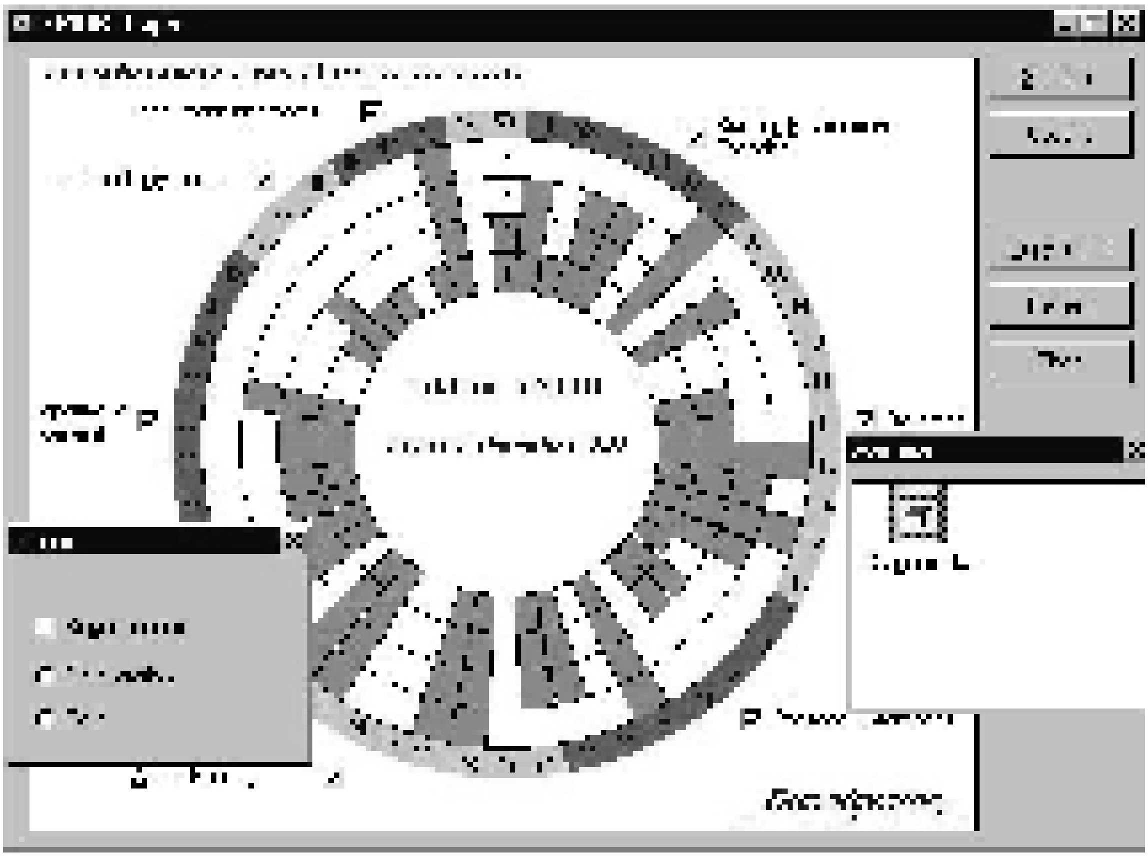


Figure 39 - EPIQR system using in Hungary (Dunaújváros)

We created connection between morphological box and graphs and there were the basic conception for our work in the field of visualisation. Our sytem-database contain 2300 details of building constructions - assimilate to system EPIQR (it has 50 elements) - it was not a simple task to manage the data-evaluation. It is an essential different between the two system. EPIQR is a user friendly software and can use really by inhabitant or building owner. The application of our system required the contribution of building experts or pathologists.

The main task of our thesaurus (graph-version) is to help the visual survey. It can be very useful to understand the hierarchy and the connections in the field of building constructions (figure 40). The thesaurus is not only necessary to the easy surveillance of the system, but also to exclude the usage of structure-name synonyms in the interest of unified handling.

We have another tool too for the quick survey of the results of the visual examination, it is the hexagonal morphological box. The box shows the actual checked constructions or all constructions of the building. The various conditions of the building constructions can be marked with corresponding colours in the box-fields (figure 41).

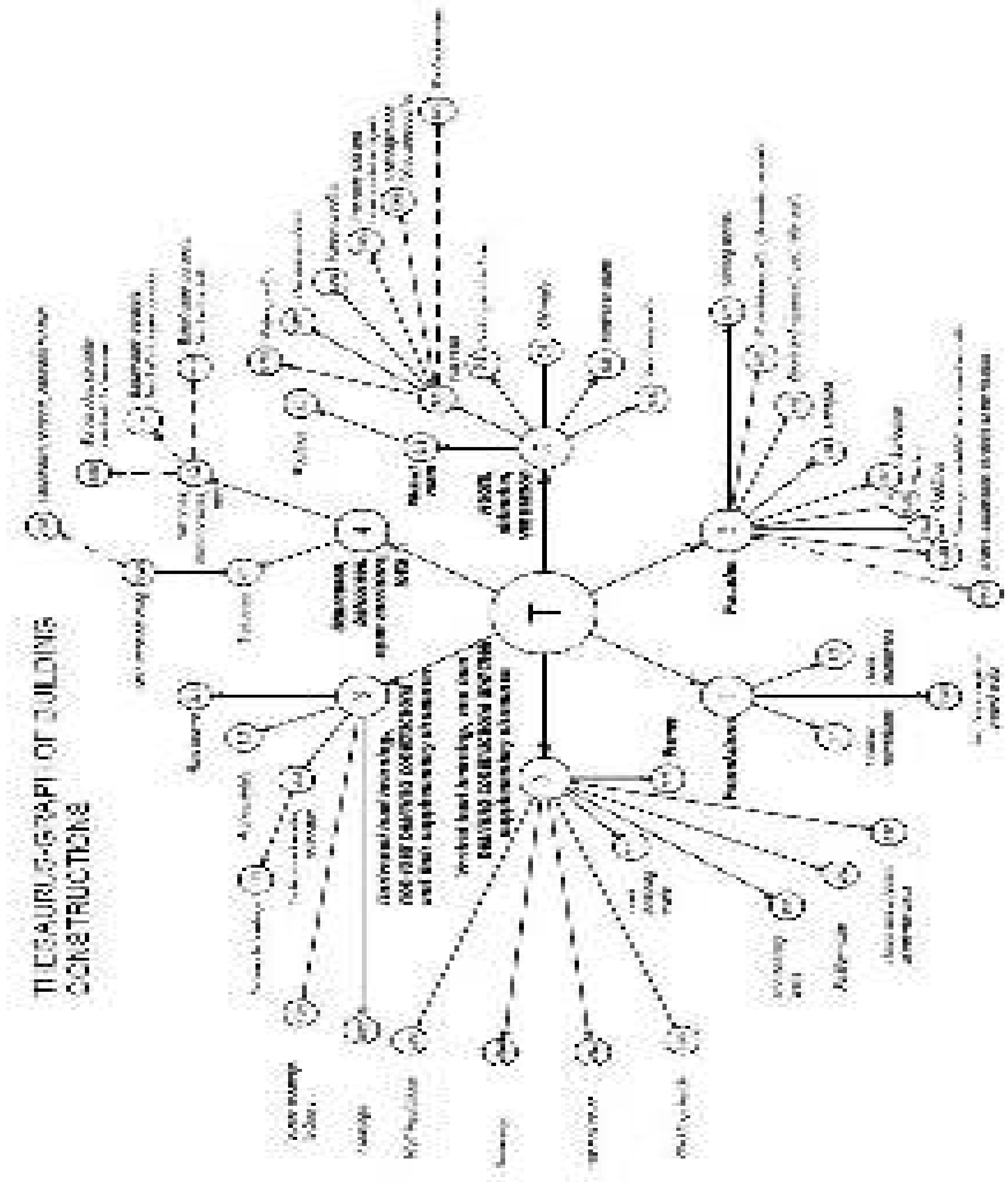


Figure 40 – Thesaurus Graph

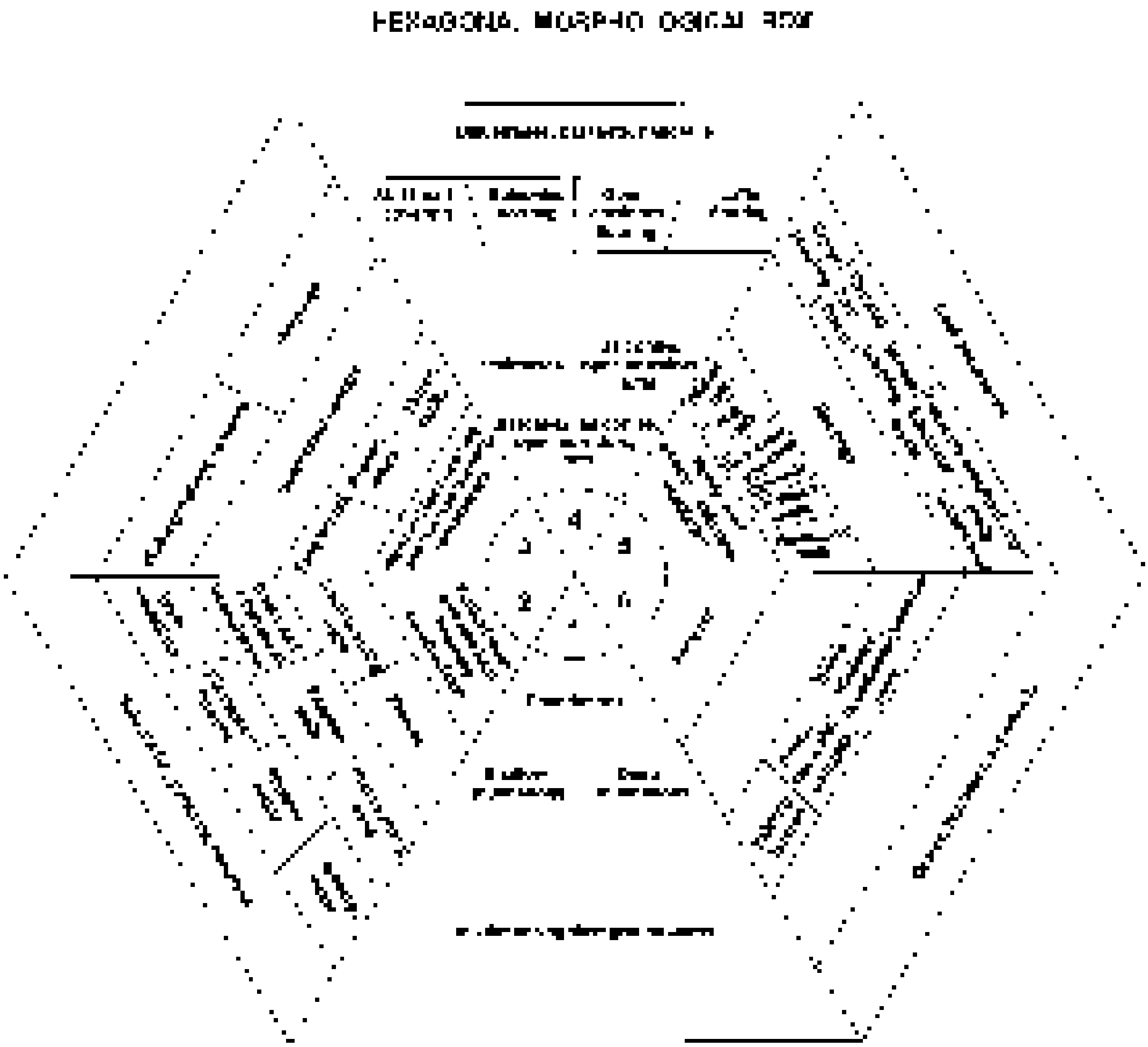


Figure 41 - Morphological box (A. Koppány)

The morphological box theory (figure 42) created by Prof. Zwicky (1966) is connected with the construction components' thesaurus denoted by the correct structure codes of these constructions' place in the hierarchy. The theory of using morphological box for data registration in the process of building diagnostic was published by the author in Hungary ten years ago. The "matrix" construction of our morphological box fits to the methodology of the visual examination and to the hierarchy of the common building constructions in Hungary 'according to Koppány (2002).

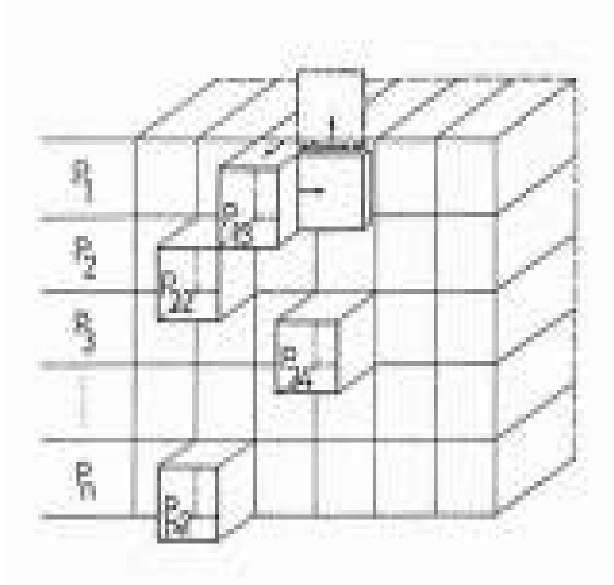


Figure 42 - Morphology (F. Zwicky)

The diagnostic system has been successfully checked in the course of a representative examination involving 60 buildings. Its installation is finished at one of the biggest building holder-operator organisation (MÁV) in Hungary.

3.8.3 EXPERIENCES OF FLAT ROOFS EXAMINATION

The majority of the defects forming on *the flat roof waterproofing and heat insulation* can be observed on the conventional insulated roof. From the point of view of the protection of substance and providing of the proper application of the building it is very important to explore and repair professionally the failures as soon as possible. Concerning the costs it is very important to explore the failures in the beginning stage because the failures which can be repaired with relatively low costs at the beginning can be repaired only with much more expenditures and together with many other structures after the extension of the damage.

It should be noted for example, that experts should check the waterproofing at least yearly because several extended and expensive damages can be prevented with this care. The typical failures of the roof can be systematised according to various points of view.

The analysis can be performed by the layers of the layer construction of the roof insulation and water-proofing or according to the contribution to the creation of the roof insulation (e.g. material manufacturing, planning, execution, operation), but it can be carried out according the so called weak points, details of the structural nodes.

Before introducing the diagnostic procedures and testing methods applied for the flat roof construction it is reasonable to determine some principles in connection with the examinations as follows:

- The examination mustn't inhibit the proper use of the building;
- The examination should be quickly performable with easily usable tools;
- During the whole process of the examination the least possible damage can come out in the flat roof water-proofing;
- If the destructing examination is unavoidable it can cover the least possible area and the place of sampling should be immediately repairable (in a waterproof way).

The diagnostic work can consist of several phases - which are important from the end point of view. At first before the examination on the spot it is reasonable to inform on the basic data, structures and building conditions of the building to be examined. In case of old roof it is not always possible since the plans and other documents could get lost and they cannot be often reconstructed. In a significant part of the cases the structural character, layer construction, the used materials and the technologies should be identified during the examination on the spot.

During the visual examination the visual failures should be discovered then the analysis of the operation of the structure can lead to the determination of the more complex causes of the failures.

During the visual examination the identification of the place of leak for large discontinuities (damages) on the water proofing of direct layer order has generally no difficulty. In case of quick examination the condition of the roof water-proofing is determined basically with visual examination, completed with a deteriorate free instrumental measurement if necessary (figure 43).

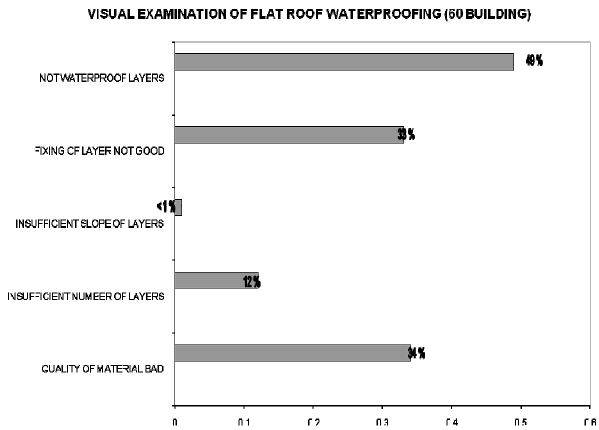


Figure 43 – Flat Roof Examination

For comprehensive examinations the procedure covers the all structural and complementary elements of the roof. The condition, load capacity, deformation of the bare floor should be examined, the building physical properties of the floor structure, etc. should be evaluated.

There are a lot of interesting data from the examination of 60 flat roof constructions. This figure shows the characteristics of frequency of the typical defects at the examined old flat roofs. The greatest number of defects were in the expansion joints area, nearly fifty percentage. The age of the examined roofs was on average 20 years. The roofs of the older industrial building had the worst condition, most of them were in bad repair.

So in order to maintain the condition, safe and durability of the flat roof water-proofing and insulation all significant factors should be examined even with a deterioration examination if necessary. It can happen that the diagnostics are started with a visual examination performed within the frame of a quick examination and to determine exactly the causes of the abnormalities, defects observed during the examination a complex examination is required.

3.8.4 CONCLUSION

In the paper is reported the development and structure of a field based survey methodology by the research group at the Széchenyi István University as practical diagnostic decision support tools. The new system was developed for the one of the biggest building holder-operator organisation in Hungary. The diagnostic system firstly based on a visual examination on the spot. At the beginning of the developing work an important requirement was the visual demonstration of the examinations' results. It was expected from the tools of system to be able to show the general conditions of the buildings or the condition of selected constructions. In the process of visual examination the experts have a big amount of data. For the effective handling and using the data the research group of the university created a registration subsystem with tools:

- Morphological box for building constructions and
- Thesaurus of building construction (connections with the morphological box).

The morphological box as a diagnostic tool wasn't used earlier in Hungary. The first probation of this tool has successfully happened and our client, the building holder-operator has installed this tool in his data registration subsystem.

Using of this tools the experts can survey the connections of the examined constructions and can use also a clear visual survey of the different durability of the existing constructions. Some details from the results of the visual examination of 60 different flat roofs can illustrate the efficiency the new subsystem.

It would be proper if the results of the constructional diagnostics, the experiences of the pathologic analyses make easier the work of experts using our registration subsystem. The practical diagnostic decision support tool can help choose the appropriate corrective maintenance procedures, it is once which remedy to the real causes of the failure.

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3.9 NON (MINOR) DESTRUCTIVE METHODOLOGIES APPLIED TO THE STUDY AND DIAGNOSIS OF MASONRY STRUCTURES OF THE BUILT HERITAGE

(Ignacio Lombillo, Luis Villegas and Clara Liaño)

3.9.1 INTRODUCTION

Cultural heritage conservation is considered as a fundamental principle of modern societies' cultural life. In recent years, extensive research has been done on this area, leading developments on inspection, non-destructive testing, monitoring and monument structural analysis.

On the other hand, old buildings analysis implies significant challenges due to the complexity of its geometry, variability of traditional materials properties, different construction techniques, lack of knowledge about existing damage, and how certain actions affect throughout their life to buildings.

These challenges mean that architectural heritage buildings are subject to diagnosis and refurbishment difficulties, which limit the application of standards and construction guidelines. That is why the understanding, the analysis and the historic buildings' repair, are considered as one of the most important challenges of modern architects and engineers.

Would it be reasonable to operate a patient without objective evidence of the illness that suffers? In that case, why do we intervene in our cultural heritage without knowing the causes that have initiated its pathological processes?

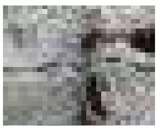
Answering to this question, interventions in old buildings, because of its fragility, require accuracy, detail and a special education in the development of a previous diagnostic study, in order to give support to decisions to be adopted on intervention techniques.

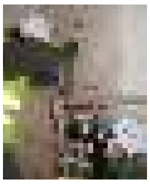
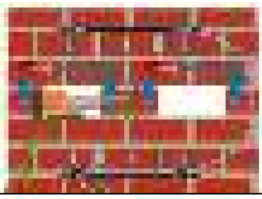
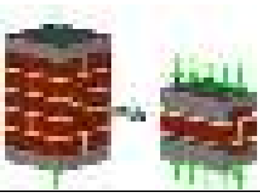
In this process, it is essential the phase survey - analysis, because it is at this stage where the hypothesis are set out and verified with calculations and tests. Within this phase, it should pay special attention to experimental survey, since such inspection contributes to both obtaining input parameters of the model analysis, and contributes to calibrate it using the experimental verification of the results obtained analytically at certain checkpoints.

Moreover, it is desirable that such experimental survey is performed of the least intrusive way as possible for the construction, greatly in the case of monumental constructions.

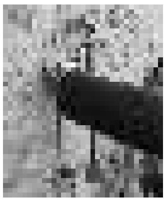
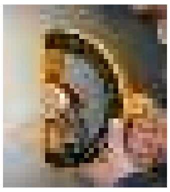
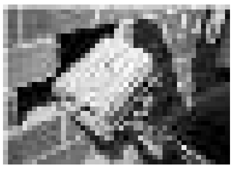
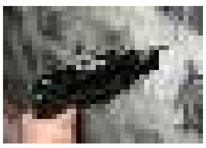
Within the general process of intervention on old constructions, this chapter insists on the on-site experimental survey stage, through Non (Minor) Destructive Methodologies.

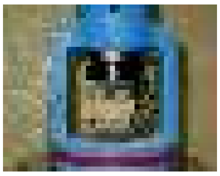
3.9.2 TECHNIQUES BASED IN MECHANICAL CRITERIA

TECHNIQUE	FOUNDATION	OBJECTIVES	ADVANTAGES	DISADVANTAGES
Simple flat jack 	Relaxation of stress.	Local stress associated to a determinate cutting plane.	Method provides quantitative results, which can be applied directly to numerical evaluation of the structural element, besides it is useful for the numerical models calibration.	Test generates little damage which it is easily repairable.

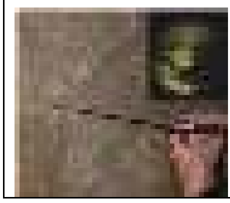
TECHNIQUE	FOUNDATION	OBJECTIVES	ADVANTAGES	DISADVANTAGES
Double flat jack 	In situ compressive test of a specimen of masonry.	Deformational parameters (Elasticity modulus and Poisson's ratio). Estimation of the compressive strength.	Method provides quantitative results, which can be applied directly to numerical assessment of the structural element (input data for numerical models). In combination with simple flat jack test could be estimated the masonry safety.	Test generates little damage which it is easily repairable. Test process is relatively tedious.
Shear Test (shove test or push test) 	In situ shear test of a specimen of masonry for different levels of vertical load.	In situ measurement of masonry mortar joint shear strength index. ζ-σ relationship	Method provides quantitative results, which can be applied directly to numerical assessment of the structural element (input data for numerical models).	Test generates little damage which it is easily repairable. Test process is relatively tedious
Hole drilling 	Relaxation of stress.	Local stress.	Method provides quantitative results, which can be applied directly to numerical evaluation of the structural element, besides it is useful for the numerical models calibration.	Method requires complementary tests.
UIC Test 	Compressive strength of a cylindrical masonry sample (D150mm).	Estimation of the compressive strength and deformational parameters (Elasticity modulus and Poisson's ratio).)	Method provides quantitative results, which can be applied directly to numerical assessment of the structural element (input data for numerical models).	Test generates larger damage than previous ones. Cylindrical masonry sample could be damaged during the extraction process. Test seems to underestimate the compressive strength.
FreD 	Relaxation of stress and in situ compressive test of a specimen of masonry.	Local stress. Deformational parameters (Elasticity modulus and Poisson's ratio). Estimation of the compressive strength.	Method provides quantitative results, which can be applied directly to numerical assessment of the structural element (input data for numerical models, besides it is useful for the numerical models calibration). Test estimates the masonry safety.	Test generates larger damage than previous ones. Test process is tedious. Test does not seem to be suitable on irregular masonry.
Masonry dilatometer 	Probe exercises a known radial stress versus the surrounding material.	Deformational parameters (Elasticity modulus and Poisson's ratio). Estimation of the compressive strength	Method provides quantitative results, which can be applied directly to numerical assessment of the structural element (input data for numerical models). In the case of multi-leaves masonries the test complements double flat jack test to characterize the internal leaf.	The produced damage in the masonry depends of the used dilatometer.

3.9.3 TECHNIQUES APPLIED TO THE MORTARS CHARACTERIZATION

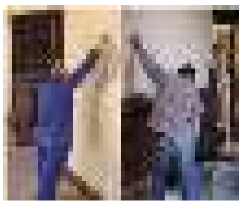
TECHNIQUE	FOUNDATION	OBJECTIVES	ADVANTAGES	DISADVANTAGES
Penetration resistance 	Relation between mechanical properties of the mortar and its penetration resistance.	Providing an idea about the mortar quality.	Test procedure is quick and it has a reduced cost.	Test provides a qualitative indication about the mortar quality. It is necessary developing previous correlations.
Sphere impact 	Relation between mechanical properties of the mortar and its energy absorbed when a device impacts on its surface.	Providing an idea about the mortar quality.	Test procedure is quick and it has a reduced cost.	Test provides a qualitative indication about the mortar quality. It is necessary developing previous correlations.
Rebound tests 	Relation between mechanical properties of the mortar and its energy absorbed when a device impacts on its surface.	Providing an idea about the mortar quality.	Test procedure is quick and it has a reduced cost.	Test provides a qualitative indication about the mortar quality. It is necessary developing previous correlations.
Pull-out test or helix test 	Relation between mechanical properties of the mortar and the pull-out force to extract a device which had been previously introduced in the mortar.	Providing the pull-out strength of the mortar and, as consequence, qualitative indication about its quality.	Test procedure is quick and it has a reduced cost.	Test provides a qualitative indication about the mortar quality. It is necessary developing previous correlations.
Bond test method 	Aplication of eccentric loads.	Test provides a estimation of mortar's bending strength.	Method provides quantitative results, which can be applied directly to structural assessment.	Test process is tedious.
PNT-G 	Correlation between the lime mortar's strength and the consumed energy in drilling a calibrated hole.	Test provides a qualitative indication about the mortar quality.	Test procedure is quick and easy, but it has a major cost than the previous ones.	Test provides a qualitative indication about the mortar quality. It is necessary developing previous correlations.

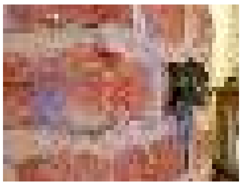
TECHNIQUE	FOUNDATION	OBJECTIVES	ADVANTAGES	DISADVANTAGES
Microdrilling 	Correlation between the mortar's drilling resistance and its strength.	Test provides a qualitative indication about the mortar quality.	Test procedure is quick and easy, but it has a major cost than the previous ones.	Test provides a qualitative indication about the mortar quality. It is necessary developing previous correlations.
Confinement method 	Compression test of a mortar portion confined between two portions of a much more rigid material.	Compressive strength of the mortar.	Method provides quantitative results, which can be applied directly to structural assessment..	It is difficult to get a sample without altering its properties. Test process is tedious because of the lime mortar's fragility.

3.9.4 VISUAL INSPECTION TECHNIQUES

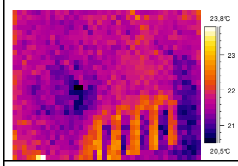
TECHNIQUE	FOUNDATION	OBJECTIVES	ADVANTAGES	DISADVANTAGES
Endoscopy 	Internal visualization of masonry elements and the conditions of the materials around holes drilled in those elements, from outside.	Defects' size, internal voids, masonry wall's morphology (multi-leaves masonries), etc.	Method allows "looking and recording" what cannot be seen from outside. Preventive screening. It is very effective, causing minor damage for a moderate cost.	Although it exists a wide range of equipments and prices, most suitable in quality and performances have an expensive cost. In equipment's ordinary use it is possible damaging it or losing the vision device.

3.9.5 TECHNIQUES BASED IN ACOUSTIC WAVES PROPAGATION

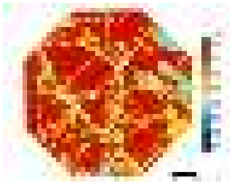
TECHNIQUE	FOUNDATION	OBJECTIVES	ADVANTAGES	DISADVANTAGES
Ultrasonic test 	Measure of the ultrasonic wave's propagation time. It is not suitable to assess heterogeneous materials.	Test allows the physical and mechanical properties estimation through correlations with ultrasonic wave velocity. Velocity range is linked with material quality.	Test procedure is quick and relatively easy.	Test provides a qualitative indication about the masonry quality and its mechanical properties.
Sonic test 	Measure of the sonic wave's propagation time. It is more suitable than ultrasonic test to assess heterogeneous materials.	Qualifying masonry structures, detecting internal voids and defects, controlling effectiveness of injection processes in masonry structures, etc.	Test procedure is quick and relatively easy.	Test provides a qualitative indication about the masonry quality and its mechanical properties.

TECHNIQUE	FOUNDATION	OBJECTIVES	ADVANTAGES	DISADVANTAGES
Impact echo test 	Studying sonic or ultrasonic wave reflection in interfaces with different acoustic impedance.	Qualifying masonry structures, detecting internal voids, defects or interfaces between different materials, etc.	Test procedure is quick and relatively easy. Test can get to estimate geometric dimensions and locate defects with uncertainly.dimensions and locate defects with uncertainly.	Test supposes certain complexity in the results interpretation.
Acoustic emission 	Detection of transient energy waves emitted by a material as result of its stresses redistribution.	Evaluation of damage and monitoring of its evolution in masonry structures.	Test allows assessing the evolution of the damage's level presented in masonry structures.	Test supposes complexity in the results interpretation.

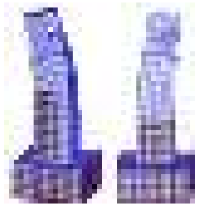
3.9.6 TECHNIQUES BASED IN ELECTROMAGNETIC WAVES PROPAGATION

TECHNIQUE	FOUNDATION	OBJECTIVES	ADVANTAGES	DISADVANTAGES
Infrared termography 	Display of the infrared radiations of electromagnetic spectrum which are invisible for the human eye.	Humidity detection, location of blinded windows or doors, cracks identification, etc.	Test does not suppose physical contact. Test procedure is quick. Test gives very visual results.	Quality thermo-cameras are expensive. Sometimes, it is not easy the interpretation of the thermo-graphic images.
Radar 	Studying electromagnetic wave reflection in interfaces with different dielectric properties.	It is useful to detect zones with moisture, voids, or other discontinuities, as an alternative to ultra-sonic tests. It also allows the detection of different materials, such as steel or wood, inside the masonry.	Test procedure is quick. Test can get to estimate geometric dimensions (measurement of thicknesses in masonry elements) and locate defects with uncertainly.	Test supposes complexity in the data processing and results interpretation.
Geoelectric techniques 	Changing of the electric resistivity.	Detecting internal voids and defects, controlling effectiveness of injection processes in masonry structures, etc.	Test can get to estimate geometric dimensions and locate defects with uncertainly.	Test supposes complexity in the data processing and results interpretation. Test supposes drilling several holes in the masonry element under study.

3.9.7 TOMOGRAPHIC TECHNIQUES

TECHNIQUE	FOUNDATION	OBJECTIVES	ADVANTAGES	DISADVANTAGES
Tomographic techniques 	It is a computational technique what supposes processing of a large amount of data. The aim is to reproduce the internal distribution of a physical property of an object through superficial measures (acoustic, radar, etc.).	Technique provides a distribution map of a physical property (for example acoustic wave's velocity) in the interior of a masonry element. Technique allows detecting voids and defects, etc.	Technique provides full information of a masonry element what allows to locate voids and defects with uncertainly.	Test supposes complexity in the data processing and results interpretation.

3.9.8 DYNAMIC CHARACTERIZATION

TECHNIQUE	FOUNDATION	OBJECTIVES	ADVANTAGES	DISADVANTAGES
Dynamic characterization 	Obtaining the main vibration frequencies.	Evaluating dynamic properties of a masonry element.	Method provides quantitative results, which can be applied directly to numerical evaluation of the structural element, besides it is useful for the numerical models calibration.	Relatively complex test and, in general, it requires large amount of time to data recording.

3.9.9 MONITORING TECHNIQUES

TECHNIQUE	FOUNDATION	OBJECTIVES	ADVANTAGES	DISADVANTAGES
Monitoring 	Control of the temporal evolution of a determinate property (through the using of sensors).	Knowledge of the temporal evolution of the structure movements, the temperature variation, etc.	Techniques provide quantitative results which can be used for the numerical models calibration. Studying the data's evaluation allows to set up safety criteria.	Recording data process should be extended for enough time to get meaningful conclusions, as consequence, monitoring duration usually is large.

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3.10 APPLICATION OF INFRARED THERMOGRAPHY TO THE DIAGNOSIS OF FAÇADE RENDERING DETACHMENT

(Sara Stingl de Freitas, Vasco Peixoto de Freitas and Eva Barreira)

3.10.1 INTRODUCTION

Render detachment is a common pathology in façades. Early accurate diagnosis is essential to eliminate defects and reduce repair costs. In this context, non-destructive techniques are important for inspection purposes.

Infrared thermography is a non-destructive technique that has been applied to buildings for some decades as a valuable diagnostic tool (Hart 2001). Thermographic cameras capture the energy emitted by objects and convert it into an electrical signal and finally into a visible image in which each level of energy is represented on a colour scale (Meola and Carlomagno 2004). This technique may be used to assess the floor covering comfort, detect insulation defects, air leaks, water infiltrations, thermal bridges and heat loss through windows, and to inspect heating systems (Barreira and Freitas 2007). However, the technology has potential applications that have not yet been completely explored, such as the detection of detachments in façades (Cerdeira et al. 2011) (Chew 1998).

3.10.2 PARAMETERS THAT AFFECT INFRARED THERMOGRAPHY

Thermograms are affected by various parameters and it is crucial to understand them in order to accurately interpret the temperature readings. The camera receives infrared radiation emitted by the surface and surroundings, and also radiation reflected by the surroundings. There are two types of parameters that can influence results: one related to the properties of the material and ambient conditions, and the other to the characteristics of the camera.

The most important parameters are as follows:

- Emissivity is a highly material-dependent surface property, which defines the material's capacity to emit energy (Avdelidis and Moropoulou 2003). There are published studies which provide tables giving the emissivity values of different materials in accordance with surface temperature and wavelength. These range from 0 (in the case of a perfect reflector) to 1 (a black body) (Maldague 2012). Most common building materials, with the exception of metals, have emissivity values over 0.8. If a quantitative analysis is required, the emissivity of each material should ideally be assessed;
- Surface colour may mask defects, as different colours absorb different amounts of solar radiation. This effect is particularly relevant when we are studying façades with colour patterns;
- Reflections on metal or glazed surfaces may distort the interpretation of the thermal image (FLIR 2011);
- Meteorological conditions such as air temperature, precipitation, wind speed, cloud cover and direct sunlight, may affect the transfer of energy, and consequently thermograms. Each thermographic record may require specific environmental conditions. For example, the assessment of thermal bridges requires stable environmental conditions, but moisture assessment requires a dynamic condition to create thermal contrast (UKTA 2007);
- The distance between the camera and object may attenuate thermal radiation for distances over 10 m (Chew 1998);
- The characteristics of the camera also affect results. There is at present a broad range of cameras on the market. For this reason, it is vital to choose the right specifications for the application required, namely: resolution, spectral sensitivity, precision and pixels;
- The calibration procedures available on the camera are also important to ensure precise measurements. These include: environmental compensation (this compensates for the influence of temperature, relative humidity and the distance between the camera and object), reflection calibration (to adjust the temperature detected) and background compensation (compensates for background reflection).

3.10.3 APPLICATION OF THERMOGRAPHY FOR DETACHMENT DETECTION

The next section describes the physics involved in detachment detection, and then provides the measurements taken in the laboratory and *in situ* using dynamic thermography (thermograms acquired at different times). Finally the *in situ* results are compared with those yielded by numeric simulation.

3.10.3.1 THE PHYSICS ASSOCIATED TO THE PATHOLOGY

Defects are identified by differences in surface temperature between areas with and without pathologies (Rao 2008). Detachment creates an air layer and thermal resistance to heat flows, which enables the temperature differential to be assessed. This surface temperature variation changes over the course of the day, as can be seen in the numerical simulation results with WUFI software (WUFI 2009) (figure 44).

Two phases can clearly be distinguished. In the heating phase, the thermal resistance caused by detachment impedes the absorbed heat from reaching the interior, which means that the surface temperature is higher in the detachment. In contrast, at the end of the afternoon, when the environmental conditions change, the façade enters the cooling phase. Now, the heat absorbed by it is prevented from reaching the surface, which means that surface temperatures are lower in the detachment, due to the reduction in thermal capacity.

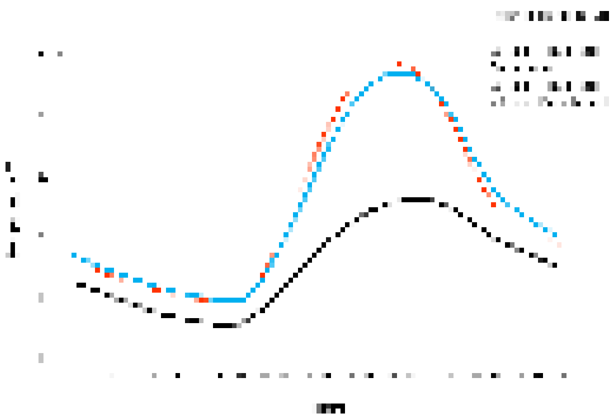


Figure 44 – Changes in surface temperature in a southward-facing façade with and without detachment over the course of one October day obtained by numerical simulation, using the WUFI calculation programme

The results presented were obtained with the climate file generated by Meteonorm (METEOTEST 2007) for one October day in Porto, Portugal. The simulated configuration involved fine polymeric render (0.004 m), an air layer (considered only for the case with a detachment of 0.003 m), cement plaster rendering (0.02 m), brick masonry (0.3 m), an air layer (0.02 m), extruded polystyrene (0.05 m) and gypsum board (0.015 m).

Figure 44 shows that, without radiation on the façade, the temperature difference between the zones with and without defects is negligible. As the exterior surface temperature increases, due to the effect of radiation, the temperature of the detachment zone increases more rapidly than zone without the defect, because of the thermal resistance provided by the air space. At around 3 pm the solar radiation on the façade causes the detachment zone to reach maximum temperature. When sunlight stops falling on the façade, the surface temperature of the detachment decreases more rapidly than that of the zone without the defect, where there is no thermal resistance from the air layer. The surface temperature of the façade continues to drop, with the zone without detachment cooling more slowly than the defective zone.

3.10.3.2 LABORATORY MEASUREMENTS

3.10.3.2.1 TEST PROCEDURE

Thermography was used to detect detachments in the laboratory under controlled conditions. For these measurements, 3 equal samples of concrete were used in which a detachment was artificially created in the coating by inserting an air layer between the support and the fine polymeric render (plastic with air bubbles) (figure 45, 46 and 47).

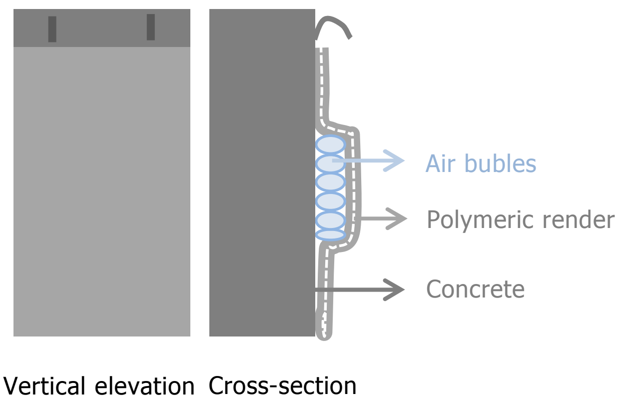


Figure 45 – Samples configuration used in laboratory tests

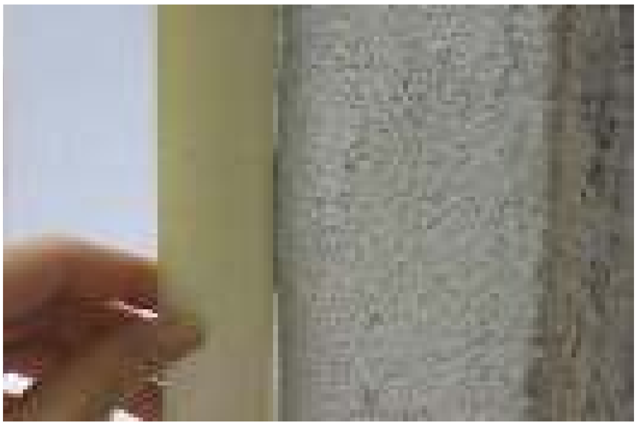
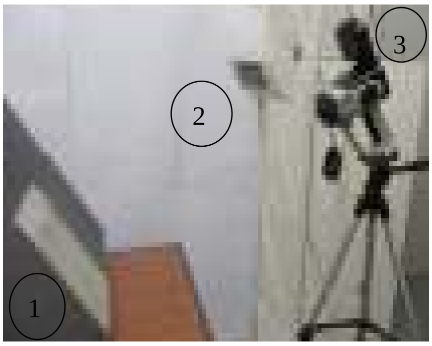


Figure 46 – Physical model of a sample used in the laboratory tests

Figure 47 – Preparation of the samples – creation of the detachment

The test involved the dynamic analysis of the surface temperature variation over time, using a 500W infrared heat source to simulate the effect of solar radiation on a façade. The three samples were placed perpendicular to the thermographic camera and heat source at a distance of 0.65 cm (figure 48). The test was performed under approximately constant environmental conditions (ambient temperature=20ºC and RH=60%) and without natural or artificial light. Thermograms were obtained on a minute-by-minute basis in three phases: without a heat source; with the heat source switched on (for 30 minutes), and after the heat source was switched off (for 70 minutes).



1 – Sample

2 – Infrared heat source

3 - Thermographic camera

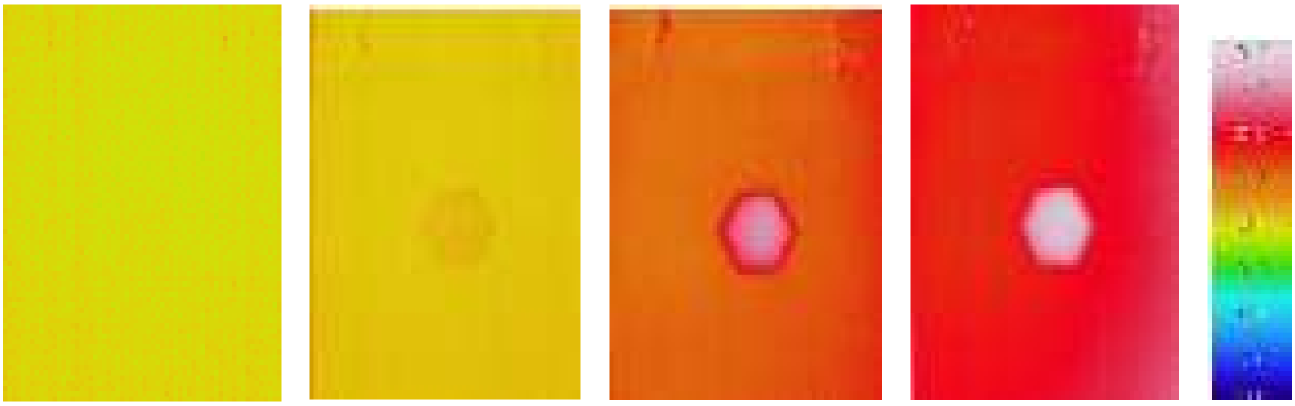
Figure 48 – Configuration of the laboratory tests

3.10.3.2.2 LABORATORY THERMOGRAMS

The thermograms obtained for the tests performed are shown in figure 49 for the heating phase and in figure 50 for the cooling phase.

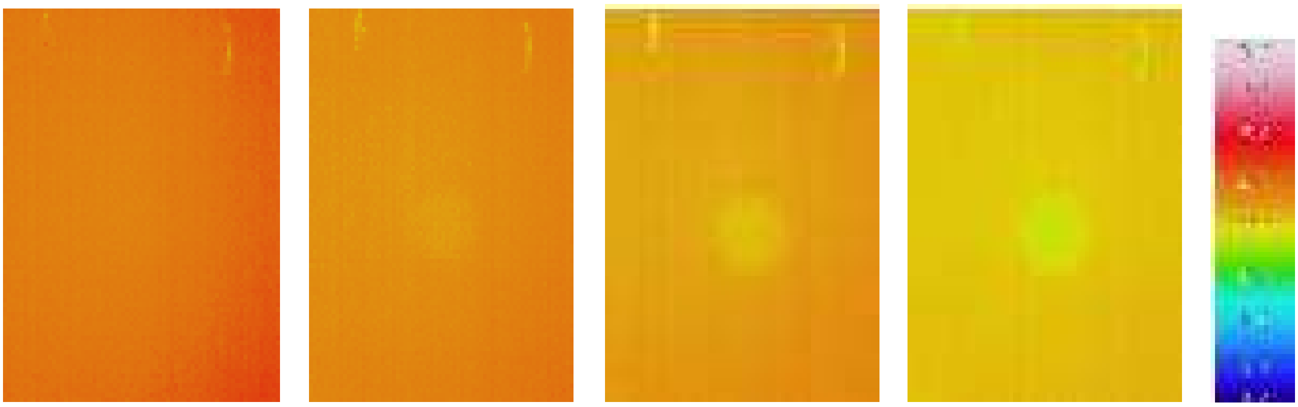
As we can see, without the action of the heat source, the detachment created in the sample is not visible. However, when the heat source is switched on, there is an increase in surface temperature throughout the sample, particularly in the zone with the defect. When the heat source is switched off, the temperature drop is greater in the detachment zone. As the cooling period proceeds, the area corresponding to the detachment becomes clearer.

Figure 51 and figure 52 show the temperature variation at a point of the detachment zone and at a point of the zone without detachment for the three samples used, with the aim of assessing the replicability of results.



a b c d

Figure 49 – Thermograms in the heating phase: a) without heating, b) start of heating, c) 10 mins after start of heating, d) 30 mins after start of heating



a b c d

Figure 50 – Thermograms in the cooling phase: a) 10 mins after heating switched off, b) 20 mins after heating switched off, c) 40 mins after heating switched off, d) 70 mins after heating switched off

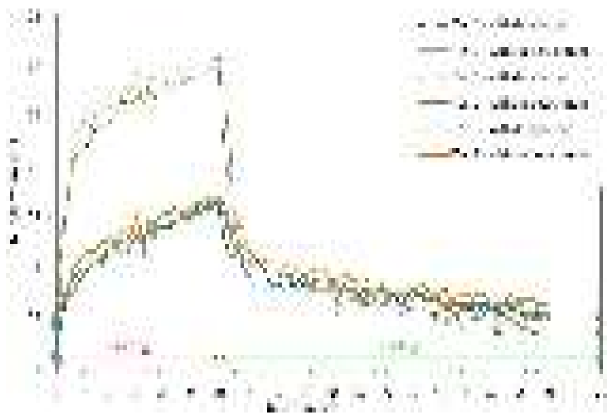


Figure 51 – Surface temperature of the three tests during the heating and cooling phases

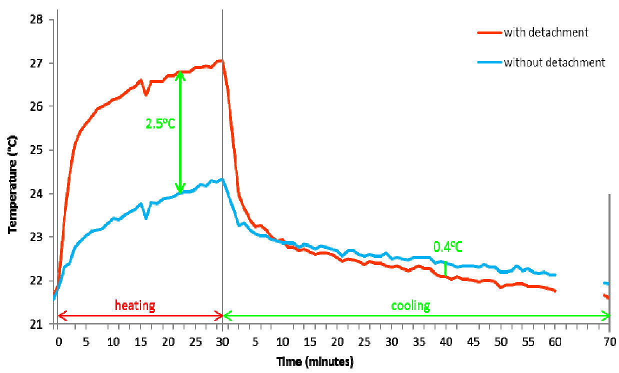


Figure 52 – Average surface temperature of the three tests performed in zones with and without detachment

3.10.3.2.3 SUMMARY

The physical model used for the laboratory tests enabled the qualitative assessment of the detachments artificially created in three samples when subjected to action from a heat source. It was found that the defect created was clearly visible through dynamic thermography (variations in the order of 2.5ºC for 30 minutes of heating). In the cooling phase, although the temperature difference between the detachment and zone without detachment was smaller (variations of around 0.4ºC after 40 minutes of cooling), the detachment was also observable.

3.10.3.3 *IN SITU* MEASUREMENTS

3.10.3.3.1 THE PATHOLOGY

A series of *in situ* tests was carried out in order to validate this method of detecting detachments in the real façades of buildings. Measurements were taken on the southern façade of a residential building in Porto, which had occasional detachments (figure 53). The façade studied was composed of a fine polymeric render (0.004 m), cement plaster rendering (0.02 m), brick masonry (0.3 m), air layer (0.02 m), thermal insulation (0.05 m) and gypsum board (0.015 m).

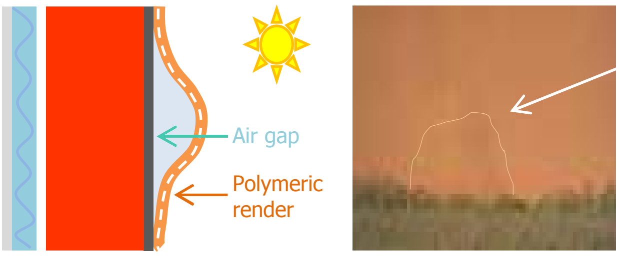


Figure 53 – Diagram of detachment studied and real detachment

3.10.3.3.2 PROCEDURE

The test procedure consisted of taking thermograms using the solar gains throughout the day in order to permit dynamic analysis. A sunny October day was chosen, and the southern façade of the building was inspected in order to detect zones with this pathology. After additional checks of the detached zones using percussion, one of the zones was selected for the placement of the thermographic camera perpendicular to the façade.

Thermograms were obtained hourly in three phases: without sunlight falling on the façade, with sunlight falling directly on the façade and after the sun had been on it.

3.10.3.3.3 *IN SITU* THERMOGRAMS

Figure 54 shows the thermograms obtained over the course of a sunny day in October. Tests were also performed on cloudy days with similar results.

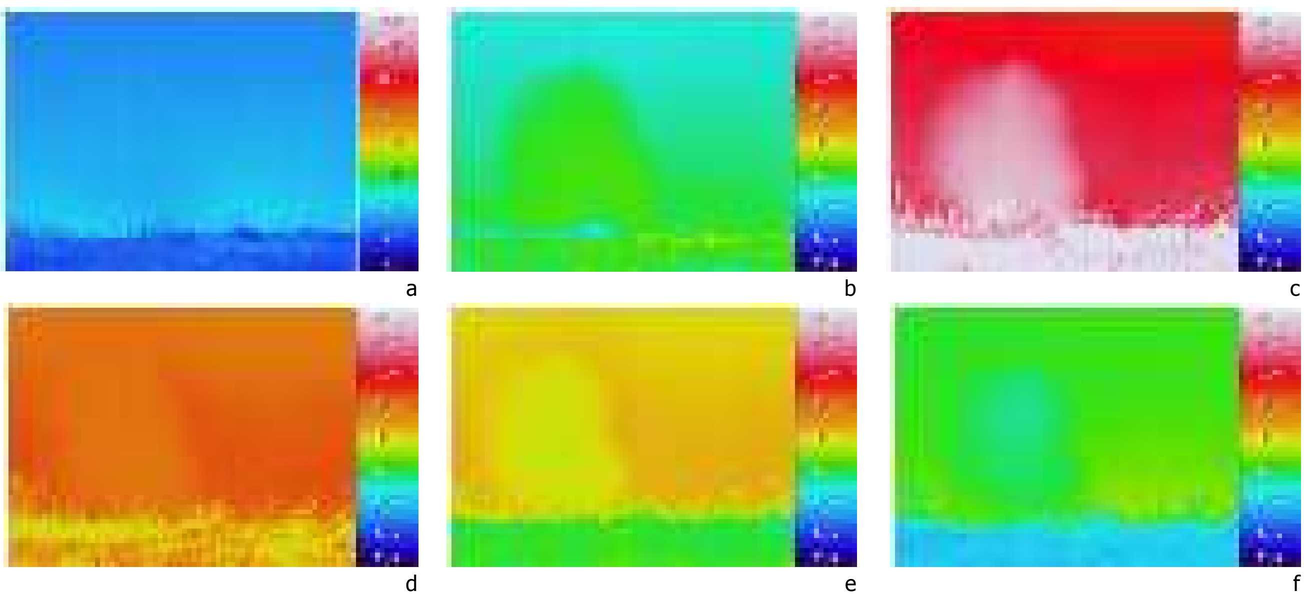


Figure 54 – Thermograms taken *in situ* through an October day: a) 9.30 am, b) 12.30 pm, c) 4.30 pm, d) 5.30 pm, e) 6.30 pm, f) 11.30 pm

3.10.3.3.4 SUMMARY

The tests carried out *in situ* produced results that were consistent with those of the laboratory tests. In the morning, when the sun does not heat the façade, the detachment is not visible. At around 3 pm, when solar radiation is at its peak, the detachment is perfectly visible, showing higher temperatures than those on the zone of the façade without detachments. On the other hand, when the façade is cooling, the detachment zone cools faster, and is therefore distinguished by lower temperatures.

These tests prove that the application of thermography in real situations leads to positive results in the diagnosis of the pathology in analysis.

3.10.3.4 COMPARISON OF NUMERICAL SIMULATION VS *IN SITU* RESULTS

The temperature change in the numerical simulation is analogous to the change in surface temperature obtained by thermography in the zone without detachment and in the zone with render detachment; that is, on a southward-facing façade, at the end of the morning, the temperature of the detachment zone is higher than that of the façade (figure 55 – b) and, in early evening, the temperature in the detachment zone is lower (figure 55 – f).

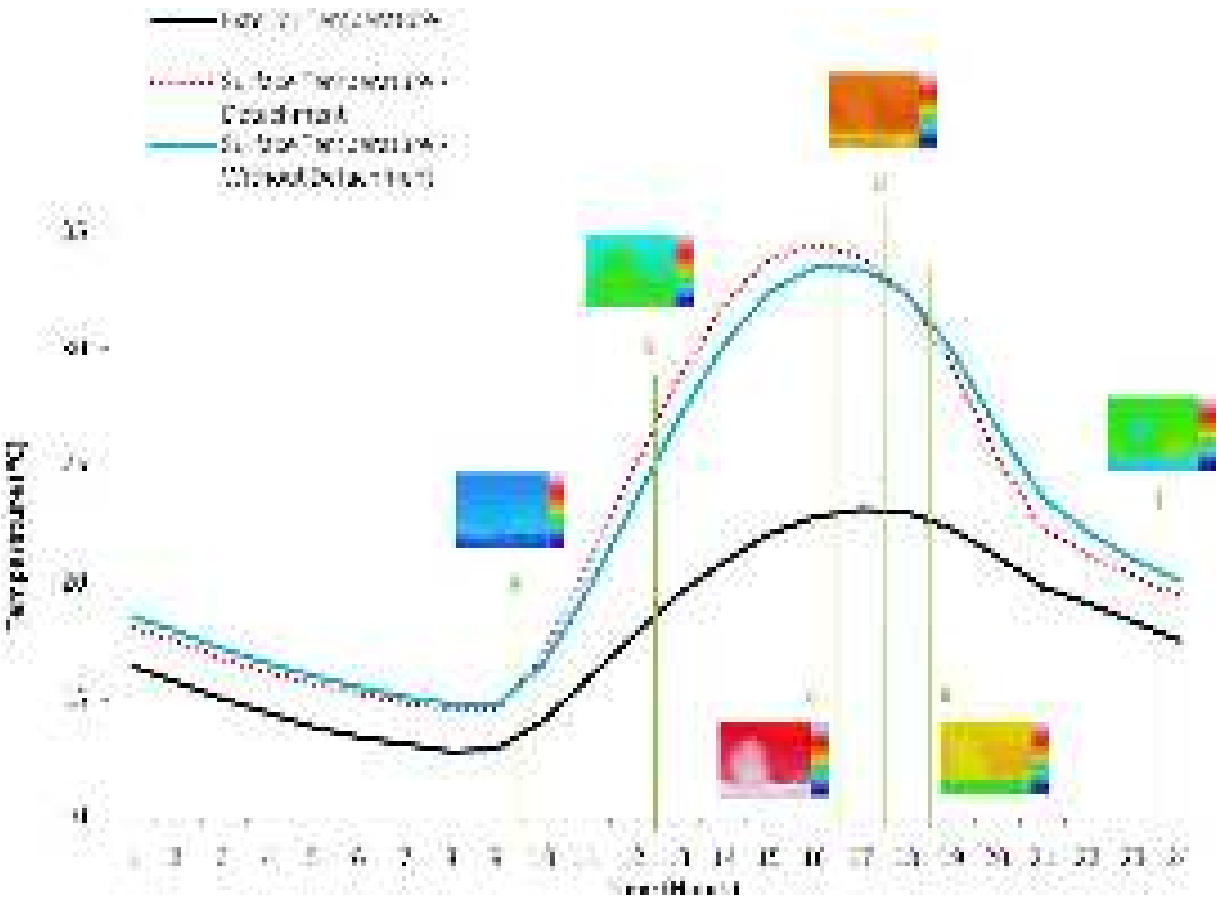


Figure 55 – Comparison of numerical simulation vs *in situ* results

3.10.4 CRITICAL ANALYSIS OF THE METHODOLOGY

This study has successfully demonstrated infrared thermography's potential for diagnosing façade render detachment. One of its main advantages is that it is a non-destructive technique, and so may be used as a preventive maintenance tool to detect detachments without having to directly access the surface.

The methodology consists of using solar radiation effect to obtain dynamic thermograms (thermograms acquired at different times). The best period for inspection was found to be during the hours of exposure to sunlight. However, the inspection may also take place after sunset or during the night, although defects will be less evident as the temperature contrast is less marked.

A qualitative analysis was adopted as it was considered to be enough to detect these defects, avoiding more complex procedures that would be necessary for a quantitative approach, and reducing some uncertainties such as the definition of *in situ* emissivity. The procedure consists of obtaining temperature differences between the detachment and zones without detachment instead of determining the exact temperature.

Before any measurements are taken, the tests must be planned in accordance with the orientation of the surface and optimization of the solar radiation effect. The *in situ* tests require greater attention due to the variability of environmental conditions. It is necessary to pay attention to parameters that may impact on the final results, such as shadows falling on the façade. Possible external influences in results should be reduced to avoid mistakes in interpreting the thermal images.

3.10.5 CONCLUSIONS

The use of non-destructive techniques is essential to detect pathologies and analyse the behaviour of façades. Façade render detachment is a very common pathology that may be assessed by infrared thermography.

Although infrared thermography has numerous advantages, it also has some limitations, given the difficulty of controlling all the parameters involved in the measurements, particularly in field conditions, where the variability is greater. Interpreting the thermograms in order to assess defects requires in-depth knowledge of the material properties, environment conditions and characteristics of the camera itself.

Thermography is a useful tool for the non-destructive diagnosis of façade render detachment, and may facilitate early detection, provided that its limitations are borne in mind.

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CHAPTER 4

INFORMATION DISSEMINATION

4.1 BUILDING PATHOLOGY CATALOGUES: DISSEMINATION OF KNOWLEDGE

(Vasco Peixoto de Freitas, Ana Sofia Guimarães and Miguel Vieira)

4.1.1 INTRODUCTION

Despite growing concerns with construction quality, as manifested by the introduction of specific regulations in the area of comfort, many recent buildings are clearly not up to standard as regards quality. Indeed, thousands of dwellings have been built recently with serious pathologies that restrict their use.

Building Pathology can be described as a scientific approach to discover what had gone wrong in a building failure. Pathologies may compromise the building in several ways, such as structural performance or indoor air quality, and require expensive interventions in order to return the building to its original state. As such, building failure is a quality indicator of the utmost importance for the construction industry. Despite the fact that each building is unique, and presents different types of failure, it is possible to identify certain patterns of failure when investigating a significant sample of buildings. Through the systematic analysis of the data collected during these investigations, it is possible to establish a reliable database which provides guidance to prevent and repair. Bill Porteous (2008) has made the following analogy "Building pathology is as important to the science of building as medical pathology is important to the science of medicine".

At a time when the building process is evolving to fast, assimilating new technologies, techniques and materials, the number of problems affecting buildings is bound to increase at a similar rate. Insufficient knowledge of materials and techniques, the stress of deadlines and the non-multidisciplinary character of the design process all contribute to the appearance of pathologies. The creation of pathology catalogues or a database would provide an invaluable contribution to preventing most problems observed in buildings and construction nowadays: by learning from past mistakes we are able to grow, assuring they become less frequent (Figure 56).

By integrating that knowledge into the process of designing new buildings, construction professionals may be encouraged to develop better materials and better building design, which incorporating innovative techniques and focus on performance besides aesthetics.

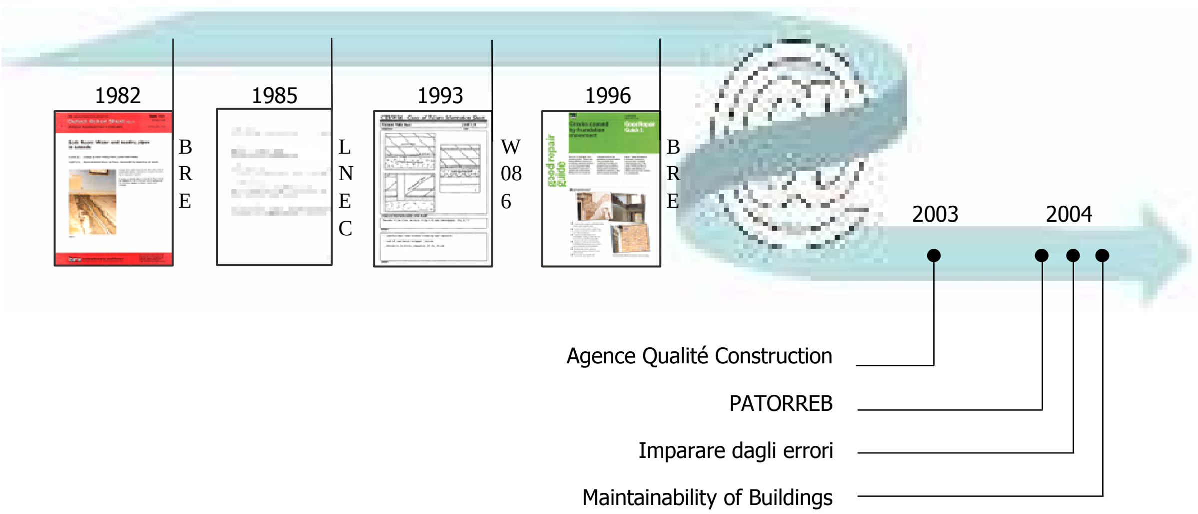


Figure 56 – Year of publishing of some building pathology catalogue

4.1.2 BUILDING PATHOLOGY CATALOGUES

As mentioned above, the continuous process of evolution and learning from past mistakes must be supported by a vast and reliable database. As such, various countries have created their own database based on data collected throughout the years, organizing them into pathology catalogues. These can be found either in printed form or online.

4.1.2.1 EXISTING CATALOGUES IN PRINTED FORM

"Defect Action Sheet" and "Good Repair Guide"

Between May 1982 and March 1990, 144 pathology records or reports, collectively entitled the "Defect Action Sheet – DAS", were prepared and published by the Housing Defects Prevention Unit of the Building Research Establishment (BRE), a British organization specialising in buildings (Figure 57).

The files, each consisting of two A4 sheets, are structured as follows:

- Description of the pathology and its causes, using diagrams and photographs wherever possible (front of sheet);
- Identification of main prevention measures, presented diagrammatically (back of sheet);
- Optional list of bibliographic references and related bibliography (back of sheet).

The Building Research Establishment (BRE) has not published pathology records in the DAS series since 1990. However, it periodically issues a vast list of publications in the area of construction in the form of files or guides known as "Digests", "Information Papers", "Good Building Guides" and "Good Repair Guides".

Figure 57 – Examples of a BRE "Defect Action Sheet" and Good Repair Guide.

"Cases of Failure Information Sheet"

In June 1993, the CIB-W086 - Building Pathology group published a document entitled "Building Pathology: A State of the Art Report" (Beukel et al. 1993). The sixth chapter of this publication was entirely devoted to pathology records or reports, pointing out the need for the systematization of knowledge in the area and the importance of learning from mistakes (Figure 58).

A format for the preparation of pathology records or reports was suggested, with the following structure:

- Component concerned;
- Failure description;
- Description of evident anomalies;
- Description of anomalies which can be monitored through instruments;
- Graphic representation (photo, drawing, draft);
- Defect description;
- Identification of the agents which caused the defect;
- Errors;
- Specific fault tree and diagnostic report.

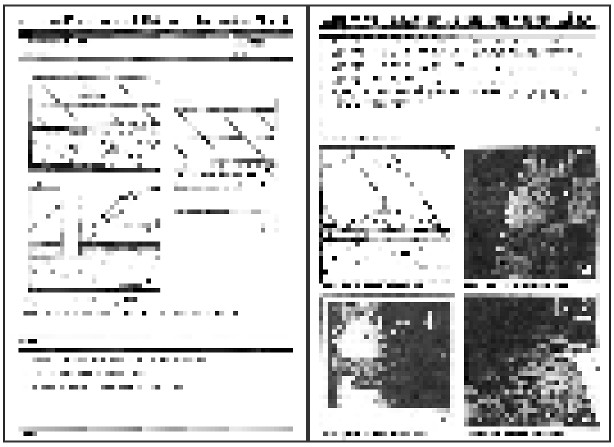


Figure 58 – Example of a CIB W086 Pathology Report.

4.1.2.2 EXISTING CATALOGUES ON-LINE

"Fiche Pathologie du Bâtiment"

The records or reports entitled "Pathologie du bâtiment" were prepared and published by the "Agence Qualité Construction" (AQC), a French organisation responsible for the inspection and implementation of quality in construction, in association with the "Fondation Excellence SMA", of the SMABTP Group, a leading insurance company operating in the field of construction in France (Figure 59).

The 61 existing records or reports were created in 1995 and have been available on line since the end of June 2003. They are grouped in accordance with the parts of the building affected, namely:

- Foundations and infrastructures;
- Support structure;
- Outer walls and renderings;
- Roofs and support structures;
- Interior finishing;
- Fittings.

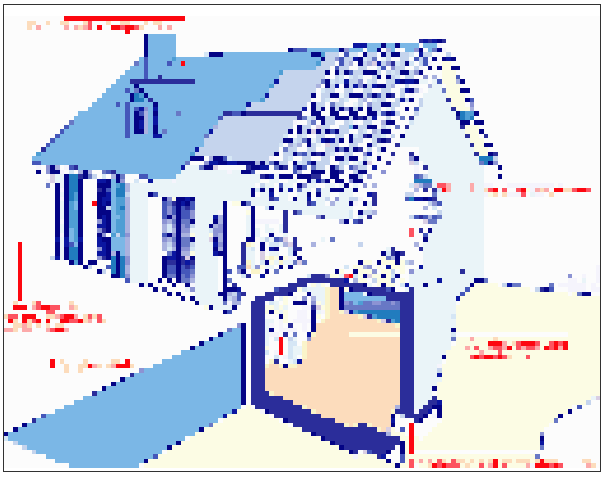


Figure 59 – Agence Qualité Construction" website

"Imparare dagli Errori"

The Italian pathology catalogue "Imparare dagli errori" was developed by Enrico de Angelis of the Department of Science and Technology of the Constructed Heritage (BEST) at the Polytechnic of Milan (Figure 60).

This site, entirely in Italian, is a platform from which files may be downloaded or printed. It is divided into the following sections:

- Materials records;
- Deterioration mechanism records;
- Pathology records;
- Case-study records;
- Anomaly records (terminology).

Figure 60 – "Imparare dagli Errori" website

"Maintainability of Buildings"

In 2004, the Building Construction Authority and National University of Singapore (NUS) developed a two-year project designed to study the problems suffered by different types of buildings in tropical climates.

The areas covered are divided into four groups: façades, wet areas, basement and rooftop. The results may be purchased on line from the site "Maintainability of Buildings" at www.hpbc.bdg.nus.edu.sg (Figure 61). The site is in English and is divided into the following fields:

- Defect Library;
- Material manual;
- Non-destructive tests;
- Maintainability scoring system.

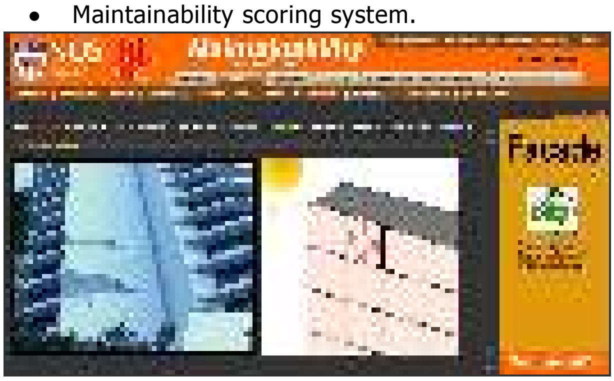


Figure 61 – Maintainability scoring system

4.1.3 PATORREB – BUILDING PHYSIC LABORATORY

The Building Physic Laboratory has created a website (PATORREB), where a Pathology Catalogue compiled by seven Portuguese Universities has been posted in Portuguese. The website has been running since June 2004 and 100 pathology reports have already been published. Prior to being published online, each report is reviewed by the Board of Editors, composed of professors from the seven Portuguese Universities. The development of the www.patorreb.com website has been supported by 30 companies and public institutions. Since August 2004, more than 150 000 consultations have been recorded (Figure 62).

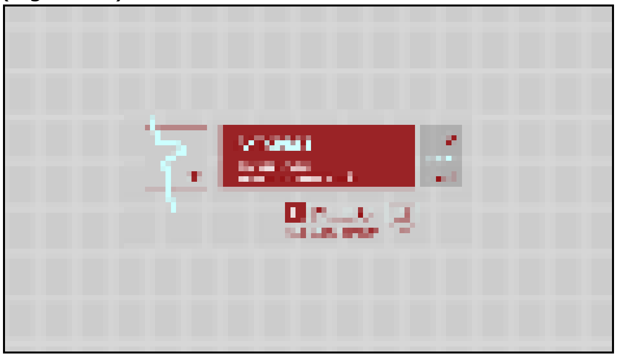


Figure 62 – Website PATORREB – www.patorreb.com

4.1.3.1 STRUCTURE OF THE WEBSITE

The site is essentially devoted to disseminating a Pathology Catalogue, which consists of a set of pathology reports. After logging in, users will be granted access to the *Pathology* area, where a schematic envelope presents the reports according to the construction element (17 elements) in which the problem manifested itself (Figure 63 and Table 3). By clicking on the corresponding red dot, the list of associated pathology reports is presented.

The website also contains a "Bibliography Area" that aims to compile the bibliographic references from the pathology reports and provide a thematic database for the website users, with references to the most relevant publications, standards and websites in the field of building pathology.

Table 3 – Elements assessed in Pathology Reports.

Reference	Construction Element
1	Pitched Roof
2	Flat roof - Inaccessible
3	Flat Roof – Accessible
4	Roof garden
5	External wall
6	Basement wall
7	Internal wall
8	Ground floor
9	Floor
10	Floor over exterior space
11	Doors and windows
12	Verge
13	Joint
14	Skylight
15	Balcony
16	Plant stand
17	Terrace parapet

Figure 63 – The Pathology screen

4.1.3.2 STRUCTURE OF THE PATHOLOGY REPORTS

The information is organized according the figure 64.

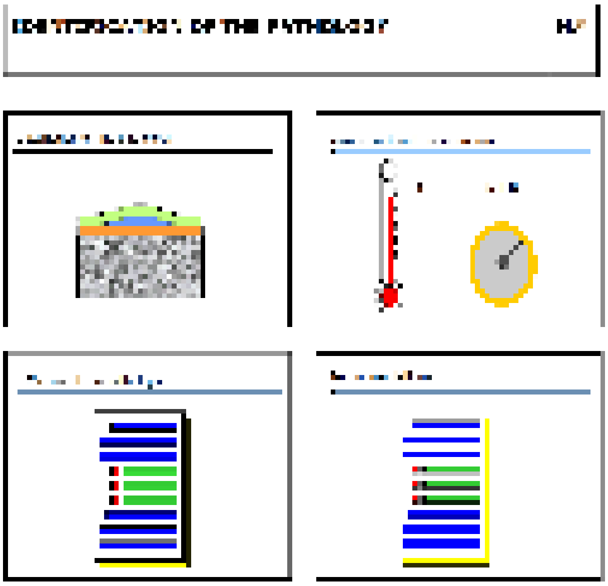


Figure 64 – Standard model of a Pathology Report.

Identification

Reports are identified through their title, which should state the pathology at hand in no more than a sentence, and also by their individual number attributed in chronological order. They also indicated the pathology type (internal or superficial condensation, higrothermal expansion, rising damp, etc.) in order to make them easier to organize.

Description

This field gives a brief description of the observed problems and onsite conditions. Relevant observations should also be included. On-site photos should complement this information.

Test/Measurements

This provides a description of the tests conducted and most important deductions and conclusions drawn. Tests are the only effective way of establishing the physical causes of pathologies.

Causes

This field presents the interpretation of the observed phenomena and their most plausible causes, based on the test results. Additional information such as charts, constructive details, etc. should be included.

Recommendations

After careful consideration and analysis of all collected data, one or more possible solutions are recommended to treat observed pathologies and/or prevent future problems. One very important aspect to retain is the fact that there is no perfect solution, let alone a unique one: the recommended solution should be the one which, in the expert's opinion, is the most suitable and viable alternative for the problem at hand.

4.1.4 CONCLUSIONS

Having demonstrated the importance of establishing accessible building pathology catalogues, we would like to invite other institutions actively working in the area to follow these examples and establish their own databases.

In order to provide easy access to the most relevant information available on Building Pathology, we are currently working on establishing a unifying central hub on the CIB website, with editable links to the most important online catalogues. This hub will enable future entries as more and more information becomes available.

4.2 BUILDING PATHOLOGY REPORT: EXAMPLES

The following includes two representative Building Pathology reports, created by the PATORREB study group and available on the website.

We choose the following reports:

— **Report A:**

Element: Ground floor

Physics: Interstitial condensations

Pathology: Loosening of PVC floor covering of a sports pavilion

— **Report B:**

Element: Internal wall

Physics: Rising damp

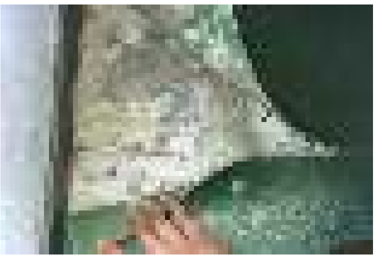
Pathology: Degradation of renders and stone due to the salts cristalization

Ground Floor – Interstitial Condensations

LOOSENING OF PVC FLOOR COVERING OF A SPORTS PAVILION

DESCRIPTION OF THE PATHOLOGY

The PVC floor covering of the ground floor of a gymnasium had come loose and started to buckle, particularly at the joints. When the covering was lifted at one of the joints, moisture was found at the interface, along with glue degradation.



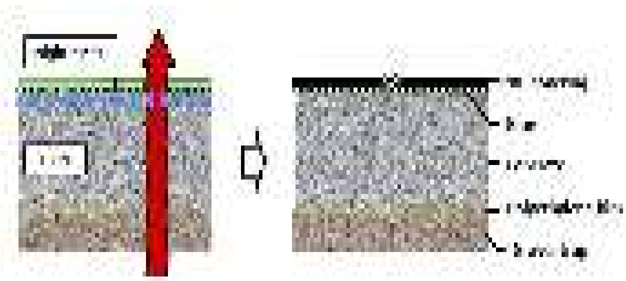
ASSESSMENT AND MEASUREMENTS

Tests were carried out to analyze floor configuration, which revealed that the PVC covering was glued directly to the concrete support layer. The floor was comprised of gravel box, concrete support layer and glued on PVC coating. A dry carotage was performed on the support layer of the covering and the moisture content determined. The concrete was found to have higher moisture content at the surface than at deeper layers. The following measurements were taken in order to determine the hygrothermal conditions:

- Water content at the support concroncrete layer;
- Temperature at the various interfaces of the ground floor;
- Indoor temperature and relative humidity.

CAUSES OF THE PATHOLOGY

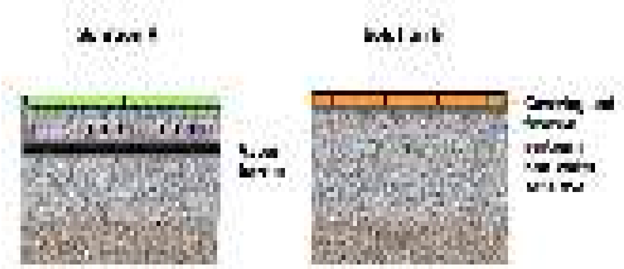
The PVC floor covering had come loose because of interstitial condensation at the interface PVC – concrete layer, caused by a lack of an effective vapor barrier and by fluctuations in the hygrothermal conditions of the indoor atmosphere of the pavilion. As the PVC floor covering was largely impermeable to water vapor, it acted as a vapor barrier located in the cold surface of the construction element, during the night, when the ground temperature was higher than the indoor temperature.The water vapor condensed at the glued interface of the floor covering, leading to glue degradation and buckling at the weakest points (joints).



RECOMMENDATION(S)

Correction of the pathology would involve the following steps:

- Removal of the PVC covering;
- Picking-up of the support layer to around 0.06 m;
- Regularization of the support;
- Application of a vapor barrier with permeance - Wp less than $2x10^{-12}kg/(m^2.s.Pa)$;-
- Placement of a polyethylene protection film;
- Execution of a small layer of concrete 0.05m thick;
- Gluing of the PVC covering;
- Remail: alternatively, the PVC covering could be replaced by a non-water sensitive covering and fixation system (B).



KEYWORDS Ground floor; PVC covering; Loosening of PVC covering; Interstitial condensations and Vapor barrier
AUTHORS Vasco Peixoto de Freitas and Marília Sousa CHECKED BY Fernando Henriques

Internal Wall – Rising Damp
DEGRADATION OF RENDERS AND STONE DUE TO THE SALTS CRISTALIZATION

DESCRIPTION OF THE PATHOLOGY

The coating of the interior walls presented moisture and degradation of renders and stone due to salts cristalization (wetting and drying process) stains on its base.




ASSESSMENT AND MEASUREMENTS

The tests conducted to identify the wall's constitution revealed granite masonry construction, with rendered and painted surface. Measurements were taken to determine the ambiences hygrothermal conditions (temperature and superficial moisture content of the wall.

CAUSES OF THE PATHOLOGY

The moisture stains on the base of the wall resulted from rising capillarity. Rising damp occurs when walls made of high capillarity materials and with no hydric break are in contact with water or moist soil. Rising capillarity continues until a balance between evaporation and capillarity is achieved. The drying flow (g) depends on the vapor concentration gradient of the air (Ca') and surface of the wall (Cs').

$g = \beta\ (Cs'-Ca')\ [kg/(m^2.s)]$

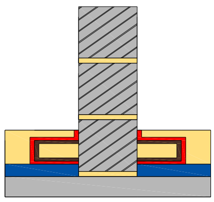
The absence of an adequate hydric break may have been the main cause of the problem.

RECOMMENDATION (S)

To minimize the problem the following intervention would be needed:

- Execution of a hydric break on the base of the wall, e.g., through the injection of hydrofuge products or pore pluggers, in order to prevent the rising of water;
- Creation of a wall base ventilation system, made of perforated tubes (e.g. in concrete), associated with a hygro regulated mechanical ventilation device.

WALL BASE VENTILATION SYSTEM:

KEYWORDS Interior wall; Granite; Moisture stains; Rising damp; Wall base ventilation and Hydric break
AUTHORS Vasco Peixoto de Freitas and Marília Sousa CHECKED BY Mendes da Silva

4.3 DAMAGE ATLAS OF CEMENT-RENDERED FAÇADES

(Pedro Lima Gaspar and Jorge de Brito)

4.3.1 INTRODUCTION

A Damage Atlas is a compilation of written and photographic information that lists the anomalies of a given building element or part. Defects are presented according to type, condition or risk, and can be used as a reference benchmark catalogue in order to assist field surveys of buildings and help understand and diagnose defects and their causes. In the last years, several of these Atlases have been developed for different building parts, namely for:

a) Traditional renders (Magalhães 2002);
b) Water-proofing (Walter 2002), including defects, their causes and preventive actions;
c) A general catalogue of building pathology, including a list of anomalies, their mechanism, causes and repair (Freitas and Sousa 2003);
d) Adhered ceramic tiles (Silvestre 2005);
e) Stone (Henriques et al. 2004);
f) Wood constructions (Haagenrud et al. 2005)

Although cement renders represent around 60% of European external claddings (INE 2001) (Balaras et al. 2004) and show a high prevalence of defects with high costs of repair (Parnham 1997) (Rita 1999) (Watt 1999) (Flores-Colen and de Brito 2003), (Gaspar and de Brito 2003), no comprehensive catalogue of defects existed specifically focusing in cement-rendered façades.

4.3.2 DAMAGE ATLAS FOR CEMENT-RENDERED FAÇADES

The research towards a Damage Atlas (DA) for cement-rendered façades has been regularly published in scientific meetings, namely presenting detailed pathology data for staining (Flores et al. 2005), for cracking (Gaspar et al. 2006) and loss of adherence (Gaspar et al. 2007). A comprehensive version of the DA has been developed within the scope of a PhD thesis (Gaspar 2009), based on the visual assessment of 100 façades in real-life service conditions, which includes:

a) A detailed description of each of the three main types of defects considered (staining, cracking and loss of adherence);
b) A methodology to quantify different condition levels associated with staining defects, based on colour variations measurement;
c) Classification of each type of defect according to the severity of its manifestations (condition level and damage extension);
d) Examples of each of the three types of defects, according to each condition level;
e) A methodology to combine the data thus collected in order to achieve an indicator of the Overall Degradation Level (ODL) for cement-rendered façades;
f) A catalogue of façades with different ODL, showing photographs, elevations and quantification of the defects identified, which can be used as a benchmark indicator for further research or professional work related to the assessment of degradation of cement-rendered façades.

4.3.3 CLASSIFICATION OF DEFECTS IN CEMENT-RENDERED FAÇADES

Defects on cement-rendered façades have been classified according to three main groups of pathologies: staining, cracking and loss of adherence. Each of these groups represents a family of defects with increasing levels of hierarchy, severity and cost of repair, despite eventual overlapping between the worst (most severe) defects of one type of defect and the lightest (less severe) defects of the next type of defect – for example, heavy staining and permanent wetting of the façade compared to light cracking, not visible to the naked eye.

4.3.3.1 STAINING

Staining defects correspond to an alteration of colour or brightness of an area of the façade when compared with nearby or adjacent areas and often occur due to the presence of water (Chew and Ping 2003). Such alterations tend to occur early in the life cycle of façades (that is, following construction or repair work) and can profoundly deface the external image of the building even if overall performance of the façade remains unchanged. Many a repair work occurs because of façade disfigurement due to staining, a pathology also recurrently referred to as "aesthetic".

Despite the large variety of manifestations of staining defects in cement-rendered external surfaces, 11 main groups have been identified (Flores et al. 2005), as shown in table 4, for which different conditions can be identified, as exemplified in table 5 for staining defects and thermophores.

Table 4 – Staining defects for cement-rendered façades

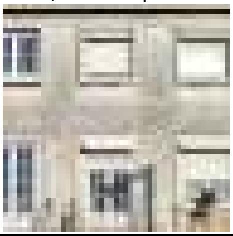
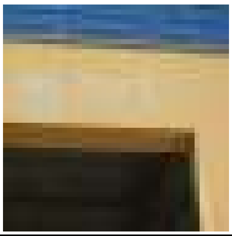
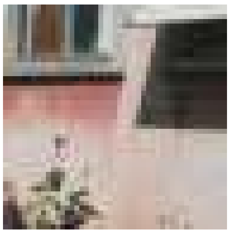
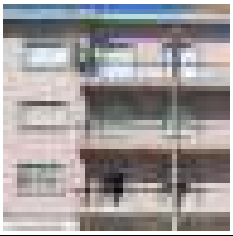
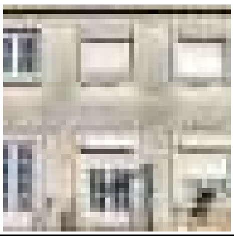
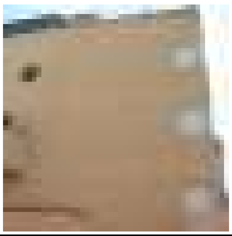
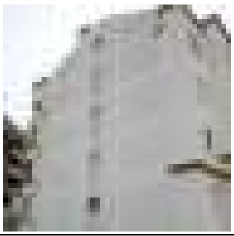
M1 Dirt / soot deposition	M2 Water runoff	M3 Water ascent	M4 Thermophorese
			
M5 Biological growth	M6 Birds / insects	M7 Efflorescence	M8 Corrosion
			
M9 Carbonation	M10 Colour alterations	M11 Accidental causes	
			

Table 5 – Examples of different condition levels for staining defects M1 and M4, from level 1 (less severe) to level 4 (most severe)

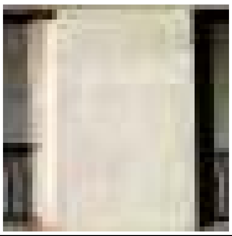
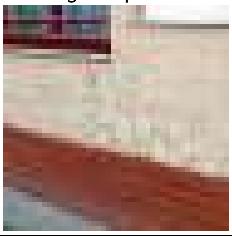
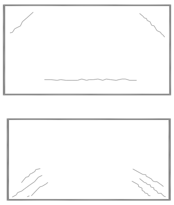
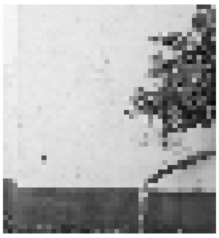
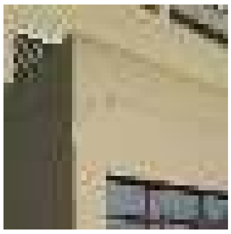
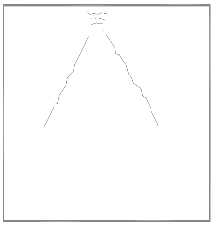
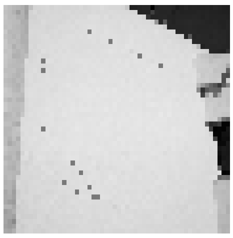
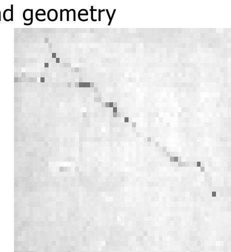
M1 Level 1	M1 Level 2	M1 Level 3	M1 Level 4
			
M4 Level 1	M4 Level 2	M4 Level 3	M4 Level 4
			

As within most building pathology considerations, classification and correction of staining defects is not always easy because one type of defect may result from several different causes. Therefore correspondence tables have been developed that relate defects to their most probable causes (Flores-Colen et al. 2005).

4.3.3.2 CRACKING

Cement-renders tend to be thin layers of cladding with little capacity to accommodate tensile forces either due to internal mechanisms (such as shrinkage phenomena associated to the hydration of its components) or to external causes (for example, differential movement of a structure due to temperature changes or foundation settlements) (Gaspar et al. 2006). As a consequence, renders are very susceptible to cracking and usually clearly display cracks despite their origin or their hazard risk. All the manifestations of this defect, as shown in table 6, need therefore to be considered, for most repair decisions tend to be based on an overall assessment of the rendered (and all degradation phenomena displayed in its surface).

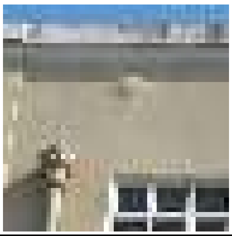
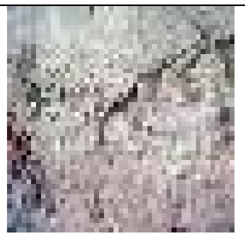
Table 6 – Cracking defects for cement-rendered façades

C1 Irregular pattern	C2 Larger irregular pattern	C3 Geometrical pattern	C4 Diagonal cracking (30º or 45º)
			
C5 Horizontal, near bottom of wall	C6 Similar to C5, with diagonals near corners of wall	C7 Vertical cracking	C8 Horizontal, top of façade
			
C9 Symmetrical pattern from middle of wall	C10 Around openings	C11 According to differences of support type, materials and geometry	
			

4.3.3.3 LOSS OF ADHERENCE

Loss of adherence may be regarded as a pathology resulting from many causes and, often, from increasing degradation levels of staining and cracking (Kus and Nygren 2002). When it occurs, renders may deform, lose their bond and / or detach from the support orthey may go through a desegregation phenomenon that leads to the washing off of its components (with either loss of cement or of sand), as shown in table 7. Loss of adherence represents the end of service life of renders since they can no longer protect the wall and, if detachment occurs, they may even endanger users and goods.

Table 7 – Loss of adherence pathologies for cement-rendered façades

D1 Loss of bond	D2 Deformation	D3 Detachment	D4 Gaps in corners, facets or vertices
[Can be detected by a hollow sound produced when render is tapped]			
	D5 Loss of internal cohesion	D6 Washing off of binder	D7 Erosion
			

4.3.4 QUANTIFICATION OF OVERALL DETERIORATION OF FAÇADES

A catalogue of defects as described above can be regarded as the basis to quantify the overall degradation of a façade and thus establish a Damage Atlas of case studies, instead of a Damage Atlas of defects.

Quantifying degradation of whole façades is a rather complex process, for seldom are the latter affected by just one type of defect. On the contrary, façades tend to experience a combination of different degradation phenomena, in which several different defects (with distinct condition levels and extensions) occur simultaneously – also sometimes referred to as a pathological state. To overcome such difficulty, a methodology was proposed that combines different manifestations of degradation in one given façade into a numerical indicator. As presented in equation (1) developed for cement-rendered façades, this indicator considers the affected areas of the façade, according to the defect type and the respective condition level. The output thus obtained is then compared to the upper theoretical degradation level of the façade – that can be obtained by the occurrence of the worst condition level for all types of defects (Gaspar and de Brito 2008).

$$S = (\sum A_n \, . \, k_n \, . \, k_{a,n}) \, / \, (A \, . \, k) \qquad (1)$$

in which,

S severity of degradation (or ODL), in percentage;

A_n extension of the façade, affected by defect n, in square meter;

k_n condition level of defect n, $K = \{ 0, 1, 2, 3, 4\}$;

$k_{a,n}$ weight of each type of defect $k_{a,n} \in R^+$; according to repair costs (refer to table 5); $k_{a,n} = 1$ if no distinction is made between the weight of defects;

k highest degradation level in K;

A area of the façade, in square meter.

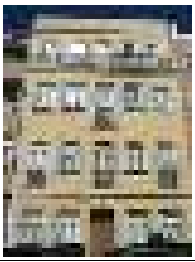
Table 8 – Relative weight of defects for each condition level, according to repair costs of renders (Portuguese Market)

Condition	Staining	Cracking	Loss of adherence
0 (best)	0,00	0,00	0,00
1	0,12	0,95	1,53
2	0,53	0,95	1,53
3	0,53	1,12	1,53
4 (worst)	0,53	1,53	1,53

4.3.5 A CATALOGUE OF CASE STUDIES

The proposed methodology has been applied in the quantification of the overall degradation level of 100 cement-rendered façades. For each case study, façades have been surveyed; defects have been identified and classified according to their condition. The affected area for each defect was also measured and registered in drawn elevations. In the end, the ODL for each façade was determined, as illustrated in table 9.

Table 9 – Façades with different ODL values

ODL = 6%	ODL = 16%	ODL = 63%	ODL = 134%
			

The façades studied can be grouped according to their respective ODL so that a pattern can be identified that describes the degradation process of cement-rendered façades, as illustrated in figure 65 and further detailed in table 10.

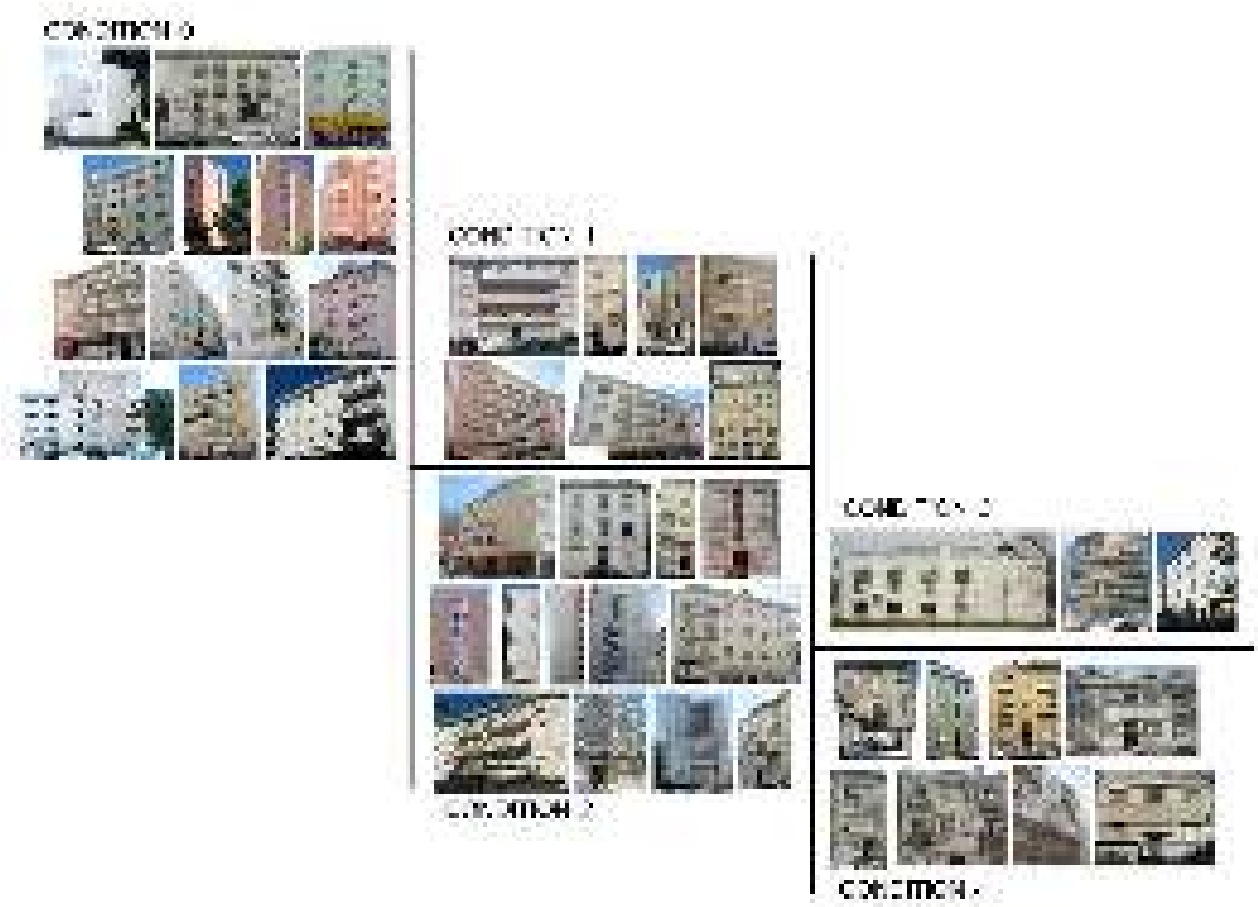


Figure 65 – Degradation pattern for cement-rendered façades, obtained by grouping case studies according to their overall degradation level

Table 10 – Classification of façades according to their overall condition level, as obtained through the indicator ODL

Description	ODL
Render with no visible signs of deterioration. Surface of render: homogeneous and straight. Colour: uniform with no dust or soot deposition.	< 1%
Light capillary cracking (0,1 a 0,25 mm). Light staining, associated with dust deposition or water runoff. Most defects of condition 1, some defects in restricted areas of condition 2.	1 to 4%
Small visible cracking (0,25 a 1,0 mm) in localized areas of the façade. Sometimes extensive dust deposition over the façade or dark streaks associated with water runoff. Changes in the colour of the surface. Possibility of localized areas of biological growth. Defects of conditions 1, 2 and (in restricted areas) 3.	5 to 14%
Possible occurrence of loss of bond (without detachment), detected through hollow sounds when the surface of the render is hit. Cracking easily detected in the naked eye (1,0 a 2,0 mm). Dark staining throughout often associated to dampness and to the presence of micro organisms and algae. Localized loss of cohesion, especially on the bottom of the façade. Defects of all conditions.	15 to 29%
Large (≥ 2 mm) and / or extensive cracking. Extensive staining, often dark and with biological growth. Loss of bond, detachment and / or loss of cohesion. Often several overlapping defects of condition 3 and 4	30 to 100%

4.3.6 CONCLUSION

Degradation Atlases are comprehensive catalogues of defects, in which the latter are listed, illustrated and described according to degradation type, mechanism of deterioration, condition, extension and risk or any combination of these characteristics.

In this chapter, a catalogue of defects of cement-rendered façades has been briefly presented. The data thus collected can be used to determine the overall degradation level of cement-rendered façades and benchmark different buildings with different condition levels. The methodology described has been effectively applied in the survey of 100 case studies. In this process, the Degradation Atlas of defects has been complemented by a Degradation Atlas of deteriorated façades. The examples studied make it possible to establish a degradation pattern for cement-rendered façades, which describes and typifies the degradation process of the latter.

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4.4 PATHOLOGY AND DEFECTS OF BUILDING FAÇADES AND ROOFS

(J. Mendes da Silva and Romeu Vicente)

4.4.1 INTRODUCTION

Building pathology, assumed as the scientific approach to building solution defects and disfunction, their causes, their evidences and evolution, as well to their consequences, includes essential information to improve prevention strategies and accurate and sustainable methodologies for rehabilitation.

The most obvious start point of this approach is the clear identification of some frequent functional defects. This section has its focus on functional defects of façades and roofs and selected, for discussion and analysis, four sub-domain (masonry walls, window sills, pitched and flat roofs). In each one is exposed a general approach and, also, is briefly discussed a practical example.

In this section, let us assume a construction defect as the situation where physical characteristics of a building element, materials or their bond solution cannot satisfy general requirements established by the 'Construction Products Directive' (89/106/EEC), ignoring, for the moment, irregular situations according to construction codes or established good practice.

The most frequent consequences (and evidences) of these defects are cracking, humidity and precoucios degradation of materials.

4.4.2 DEFECTS AND CONCEPTION OR DESIGN ERRORS

The technical world of construction tends to progressively assume that errors at the conception and design phases are noticeably responsible for an extensive number of defects that, traditionally, were imputed to the execution phase and workmanship.

This frontier remains somewhat blur and the discussion about the autonomy and qualificiation of execution teams and the importance of workmanship skills has to be permanently refreshed.

The conception phase should establish, clearly, the main guidelines and principles that design should translate into operational drawings and written documents, in an appropriate way to guide the construction phase.

New materials, new technology and new architecture require a very formal approach of requirements and constraints, to be sure that design will propose solutions that can be successfully executed and clear in terms of compatibility between elements and materials, affordable and, above all, feasible and durable.

Some defects of construction elements are due to inappropriate use or lack of maintenance. They are briefly referred in some of the following examples, but they are not the principal aim of this section.

4.4.3 DEFECTS ON MASONRY WALLS

4.4.3.1 GENERAL SCOPE

Masonry walls made with bricks or blocks (clay bricks or concrete blocks) and their traditional finishing are able to fully satisfy their requirements for long time. However, they often present expressive cracking, humidity problems and natural (or accelerated) degradation of materials.

The main reasons for cracking, in masonry walls, are: differential deformation of supporting structural elements, local high stresses or loads, support deflection (slab or beam excessive deformation), chemical incompatibility between materials, volume change due to humidity or temperature variation.

4.4.3.2 NATURAL MOVEMENTS OF WALLS AND CRACKING

One of the recurrent defects of masonry walls is cracking in consequence of natural movements (change on temperature or water content, irreversible clay brick expansion or hydraulic shrinkage of cement mortars). Irreversible movements are quite dangerous and can progress for one or two years.

All these situations tend to expand or contract the wall but these movements are both internally and externally restrained, which produces high local stresses. Within the wall, shear stresses generally create horizontal and vertical cracks at the interface block-mortar joint, cracking or crushing the blocks only if they are quite weak and if bond strength is fairly high. In spite of the complex phenomena involved, two basic expressions are essential to pre-design expansion joints and to estimate the average expected stress (tension or compression) in the wall:

$$\Delta L = L\,\alpha\,\Delta T \qquad (2)$$

$$\sigma = E\,\Delta L / L \qquad (3)$$

where: ΔL = *length variation (m); L = initial length (m);* α *= thermal expansion (m/mºC);* ΔT *= temperature variation (ºC).;* σ*= stress (kPa); E = Young Modulus (kPa).*

To estimate expansion and contraction movements it is essential to consider other factors such as air temperature and wall surface temperature, surface color and its heat absorption coefficient.

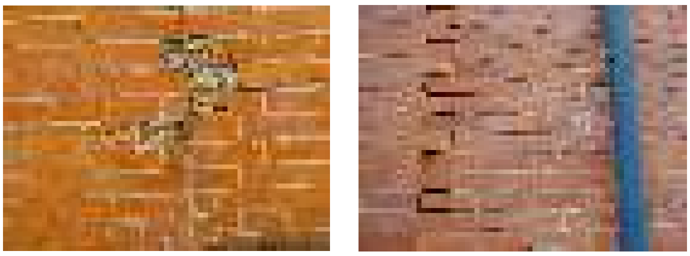
The most frequent values for all these factors are quite known but it is indispensable to carry out a specific calculation for each situation, since the combination of these factors lead to a wide range of particular situations in what concerns movements and stresses and, in consequence, the reinforcement that is needed and the recommended width of expansion joints.

4.4.4 EXAMPLES

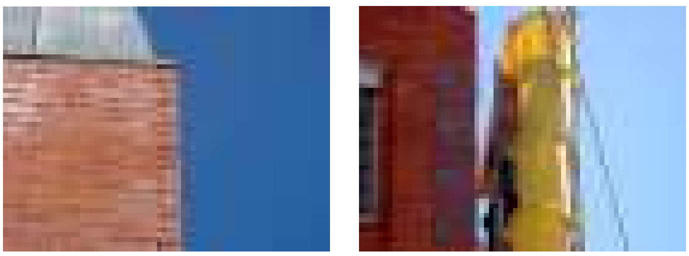
For long time, clay brick masonry walls were built inside concrete structural frames and, in consequence, the natural movements of materials produced by humidity and temperature change along the time imposed local stresses with limited consequences. The increasing use of non-restrained external walls leads to increasing defects resulting from natural movements, because the expansion is, theoretical, free. However, at singular points of the walls and in extensive walls, these movements generate high local tensions and consequent cracks (see Figure 66).

It is essential to reduce natural movements (using sound materials and protecting the walls against the most aggressive atmospheric actions) and also to reinforce masonry walls and to create adequate expansion joints with accurate design supported by calculations that consider all specific characteristics of materials, architecture and external actions.

Typical facing brick masonry walls where expansion joints are required and where irreversible expansion of fired clay brick is a real risk



Cracking and splitting of the masonry wall near the expansion joint due to its inadequate width and significant irreversible expansion of fired clay brick



Typical vertical crack at an external unreinforced corner angle as a consequence of the unequal movements of the two orthogonal masonry walls

Figure 66 – Examples of defects on clay brick external masonry walls, resulting from natural movements and inadequate reinforcement or free movement joints

4.4.5 DEFECTS OF WINDOW SILLS

The performance of building façades to rain water penetration depends, not only on its current opaque areas but, also, on its singular points, namely windows. Window sills are quite relevant for the water tightness protection of the wall. Table 11 summarizes their main potential defects and predictable consequences. Further on, some examples are briefly commented.

Table 11 – Attributes and possible defects of window sills (in what concern (A) materials; (B) transversal shape; (C) longitudinal shape; (D) connections)

Type	Attribute	Possible Defect	Consequence
A	Material porosity	High porosity	Danger of excessive absorption of rainwater
A	Physical strength	Limited strength	Cracking under ordinary actions or accidental impacts (allowing infiltration)
A	Surface roughness	High superficial roughness	It slows down water drainage and promotes infiltration
A	Durability	Very sensible (or unprotected) materials to mechanical actions, ice, corrosion, ultra-violet radiation, etc.	Early deterioration, carrying out economic, aesthetic and functional losses
B	Slope	Flat or slightly sloped sill	It slows down water drainage and promotes infiltration
B	Horn length	Insufficient dimensions of windows' stool out to the sidewall	The water is not projected far from wall surface and it is probable the occurrence of infiltration under the sill.
B	Edge	It is not a real defect but it has great influence on water drainage	The edge shape of the sill influences how far the water is projected, preventing infiltration under the sill.
B	Water fence Anti-dripping linear gap at horn under face	Lack of anti-dripping gap or insufficient width; anti-dripping gap to much close to wall surface	The water is not projected far from wall surface and it is probable the occurrence of infiltration under the sill.
B	Thickness	Very reduced thickness	High risk of cracking
C	Flatness (no side elevation)	It is not a real defect but it has great influence on water drainage	It is probable to get side infiltration, side concentrated flow and local dirtiness of the wall.
C	Upper face side gap/channel	Lack of side gap/channel	It is probable to get side concentrated flow and local dirtiness of the wall.
C	Side overlapping of the wall	Non existing or excessive reduction	It is probable to get side infiltration, side concentrated flow and local dirtiness of the wall.
D	Connection to casing side walls	No overlapping side wall/window sill or inadequate shape.	It is probable to get side infiltration, side concentrated flow and local dirt accumulation on the wall facing.
D	Connection to casing support walls	Insufficient tightness	It is probable the occurrence of infiltration under the sill.

Table 11 clearly shows that several factors can contribute to water infiltration into the wall through windows sills and their connections. Additionally, the concentration of water flow coming out from the sills leads, frequently, to local deterioration of building materials (wall finishing), to local dirt accumulation and to bioactivity (mould and lichen growth). Although, there are only known a few guidelines for the design of these protection elements, mainly based on traditional solutions and materials.

The contemporary architectural solutions and available materials impose a permanent analysis and a new approach, since traditional rules are insufficient to guide securely these news proposals, in what concerns materials choosing, geometry and execution.

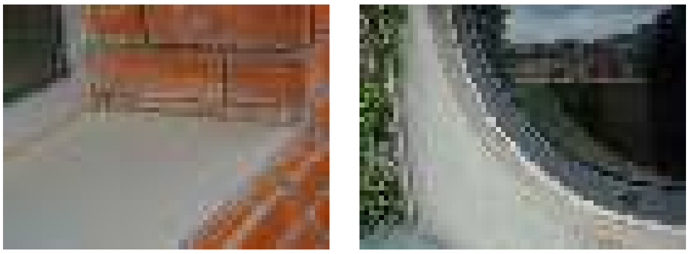
Unfortunately, in ordinary construction, many non-innovative solutions – already well described in technical documents that are frequently neglected – are designed and executed with basic workmanship errors and defects that limit the expectation of their more elementary performance (see Figure 67).

Wall deterioration due to lack of window sill

Example of flat (and inefficient) recurrent solution

Insufficient length of sill horn

Inadequate anti-dripping gap at the sill under face



Non conventional solutions with very difficult connections between different materials

Figure 67 – Examples of window sills with different shapes and materials, which functional performance is somehow compromise

4.4.6 DEFECTS OF PITECHED ROOFS WITH CERAMIC TILING SLATES

Roofing systems of a building are one of the most vulnerable parts to suffer defects, since they are exposed to climate actions (temperature, solar radiation), adverse loading conditions (wind and snow) and susceptible to chemical and biological agents (decay and staining). The main consequences that result from the roofing defects or their combination are:

- Leakage (rain penetration through particular areas: e.g. chimneys);
- Roof tiles or slates slipping, displaced or blown off by wind;
- Deterioration (delaminating, spalling and cracking);
- Early degradation of covering materials (fixing, tiling, flashing);
- Deformation of the underlying structure (sagging, distortion, spreading).

These consequences are sometimes the cause of subsequent problems that affect other parts (façade and boundary walls, neibourghing buildings, etc.).

Table 12 identifies, in greater detail, eventual defects of pitched roofing systems, associating to each iits most probable or potential origin: conception and design, workmanship and execution, service use and material quality.

Table 12 – Main defects of pitched roofs with traditional clay tiling and their relationship to its most probable origin

Defects	**Origin**
▪ Incompatible geometry of the roofing system (ceramic roof tiling)	**C**
▪ Lack of detailing of singular areas (fixings, junctions, flashing and valley gutters)	**C**
▪ Lack of technical specification for materials and execution procedures	**C**
▪ Insufficient strength and deformation of the underlying support structure	**C-E-M**
▪ Excessive or insufficient slope	**C**
▪ Missing or damaged fixings, stepped flashing and capping (edges, chimney stacks)	**E-C**
▪ Missing or damaged soakers and damp proof coursings (edges, chimney stacks)	**E-C**
▪ Incompliance of the design project	**E**
▪ Incorrect interlocking and fixing of roof coverings (tiles and slates)	**M-E**
▪ Excessive or inadequate overlapping of tiles and slates	**E**
▪ Misuse of ancillary components and accessories (corrosion, etc.)	**E-C**
▪ Inadequate use or lack of quality of materials and fixings	**E**
▪ Misalignment of roof tiles or slates	**E**
▪ Excessive use of cement mortars for tile bedding (at the ridge, hip and galleting areas)	**E**
▪ Fractured tiles (specially at edges, eaves, nips, verge and junctions)	**U-M-E**
▪ Accumulation of mould, debris and vegetation (lack of maintenance)	**U**
▪ Defective water drainage (blockage, leaking, missing and damaged gutters and piping)	**C**
▪ Laminating of roof coverings due to frost	**M-E**
▪ Slipping and movement of roofs coverings (tiles or slates)	**E-C**
▪ Lack of cross ventilation or blocking of ventilation channels/trays at eaves	**E-C**
▪ Incorrect positioning or absence of vapour barrier and sarking felt	**C-E**
▪ Absence or incorrect fixing and positioning of thermal insulation	**E-C**
▪ Precocious deterioration of materials used	**M-U**
▪ Tonality differentiation of covering materials	**M**

C (conception and design); E (execution and workmanship); M (material quality); U (service use)

The most sensitive points are areas where flashing is most necessary: chimney stacks, ridges, nips, eaves, verges, roof lighting, etc.

Pitched roofs represent a very high percentage of total roofing systems for residential building stock, new or old, consequently the durability and ease for maintenance is an important issue. Therefore, four aspects are particularly interesting when surveying:

- The conditions of rainwater disposal (gutters, profiles, hoppers and pipes);
- Ventilation and insulation conditions to prevent moisture problems;
- Fire safety and precautions (strength and precautions);
- Stability of the underlying structure (loading conditions, wind, temperature variations, etc.).

In figure 68 are presented some cases of common defects observed in recent and old buildings with pitched.

Incompatible geometry of the roofing system

Insufficient slope and the excessive use of cement based mortars

Gapping between tiles

Defective flashing

Vegetation growth

Tile/slate slipping

Figure 68 – Examples of defects for pitched roofs

4.4.7 DEFECTS ON FLAT ROOFS

Flat roof systems are particularly complex when taking into account the number of layers and the water tightness detailing and required at various singular points: abutments, verges, canopies, rainwater outlets, etc.

Among these layers the position of the thermal insulation and the weatherproof layer define the type of flat roof. The inverted warm deck roofs, presently most common, have the thermal insulation overlaid above the weatherproof membrane. Table 13 systemizes the principal defects identified into four groups over 268 flat roofs surveyed during a large campaign carried out for the central region of Portugal in 2001.

Table 13 – Main defects of flat roofs (case study for the centre of Portugal – 2001)

Type of defect	**Number of observed cases**	**%**
DEFECTS ON DECKING (PLAN SURFACE)	**76**	**28,4**
1 – Absence of a waterproofing membrane (asphalt, plastic, metallic sheeting)	11	
2 – Inadequate selection and positioning of the waterproofing membrane	9	
3 – Blistering, splitting, perforation and rucking of the impermeabilization	7	
4 – Absence of adhesion of deck covering	3	
5 – Ageing of the sarking felts, vapour control layer and DPC´s	10	
6 – Unbonding and poor overlapping of the waterproofing and felt layers	11	
7 – Deterioration of the isolating layer due to root penetration of vegetation	6	
8 – Defective and irregular support conditions and ventilation provisions	4	
9 – Problems due to wind action blow off (mats, felt layers and scoured gravel)	2	
10 – Water trapping due to condensation under vapour proofing layer	7	
11 – Water ponding (accumulation)	6	
DEFECTS AT GABLE ENDS, ABUTMENTS, VERGES AND PERIMETER WALLS	**101**	**37,7**
12 – Defective waterproofing of parapet abutment flashing	21	
13 – Defective upstands and kerb flashing	31	
14 – Defective capping at window and door sills (terrace deck)	26	
15 – Water penetration due to the absence of waterproofing of canopies	12	
16 – Water penetration due to poor or incorrect coping at parapets	11	
DEFECTS OF RAINWATER DRAINAGE DISPOSAL SYSTEMS	**55**	**20,5**
17 – Blockage of gutters and rainwater piping	8	
18 – Undersized gutters and pipes for the calculated rainwater run-off	18	
19 – Back flow of rainwater due to broken brackets, etc.	3	
20 – Leakage through rainwater outlets and piping	3	
21 – Deficient capping of vent and rainwater outlets (piping junction at deck)	23	
DEFECTS AT SINGULAR POINTS OF THE ROOF	**36**	**13,4**
22 – Defects at horizontal movement joints	17	
23 – Water penetration and leakage through rainwater drainage piping	10	
24 – Defects at skylights, roof windows and dormers	3	
25 – Water penetration through chimney stacks	6	
Total	**268**	100%

For flat roofs the identification of defects is quite difficult, therefore a more thorough investigation is required. The first signs are usually the presence of dampness and stains at the ceiling levels. In many cases leakage, due to thermal induced cracking of the deck covering or perforation of the waterproofing layer through the roof slabs damages can manifest water penetration at some distance from the point of entry.

It is important to keep in mind that flat roofs are particularly sensible to condensation problems, degradation of insulation - if not chosen correctly - and the lack of periodical maintenance. In what concerns the condensation, the design should minimize the creation of cold bridges, reducing theoretically the risk of condensation under the insulation layer. For this purpose it is also essential to use a vapor proof barrier at the hot face of the insulation system.

In figure 69 are presented some cases of common defects observed in flat roofing systems with the focus on inefficiency of draining systems.

Lack of abutment flashing

Leakage through piping or heating systems that perforates the roofing system layers

Tile cracking and poor adhesion of covering deck materials

Water ponding

Undersized rainwater outlets

Blockage of outlets due to the lack of maintenance

Figure 69 – Examples of defects for flat roofs related to the inefficiency of their draining system

4.4.8 FINAL NOTE

The contribution of façades and roofs for the external building envelope conservation and durability are crucial. However, they often present several defects and compromise their basic requirements particularly in what concerns rainwater tightness. This section briefly discussed and systematized some of these defects.

When the traditional solutions are adopted, a bibliographic review is recommended, since there are clear guidelines to design and execute, however often ignored. New proposals – in terms of architecture and materials – should be submitted to an accurate analysis based on the systematic verification of functional requirements and experimental tests to assure the desired and expected performance.

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4.5 WATERPROOFING MEMBRANE PATHOLOGY ANALYSIS AS A MEANS OF INNOVATION: THE CASE OF EUROPE

(Sergio Croce)

4.5.1 INTRODUCTION

This report presents a brief history of waterproofing membranes and flat roofs in Europe, with specific reference to Italy, starting from the 1970s. This overview is the result of 40 years of technical forensic analysis.

In the building sector the study of pathological cases makes knowledge available, which is fundamental for the improvement of the quality of the products and systems. The case of the flat roofs presented here is clear evidence of this. The study of pathologies has improved the quality of the waterproofing membrane and the research of new and more efficient and innovative materials. Just like in medicine, the study of diseases makes it possible to devise treatment systems, so knowledge obtained from negative experiences is and has been nourishment for the definition of qualification procedures and for the development of new products.

As to the current situation, potential qualities of waterproofing products are high, pathological cases tend to depend more and more on design and construction errors. In particular, design errors deal with the selection and definition of the flat roof system, besides poor attention given to details.

Starting from the 1970s, the sector of waterproofing membranes has been affected in Italy and Europe by an innovative trend which was not as clear in other sectors of the civil works. These dynamics have frequently clashed against failures that in the period of the introduction of the prefabricated membranes, in oxidized bitumen, led many public administrations to prefer pitched roofs. In those times indeed, the Italian standard UNI 9307-1, "Coperture continue. Istruzione per la progettazione. Elemento di tenuta", edited in 1988, develop a state of art of design criteria starting from an exhaustive analysis of aging factors and pathological consequences (figure 70).

These failures contributed however to innovate the sector by means of the production of new membranes which now are better controlled in terms of their durability and integration in final systems. While in the 1960s, the service life of a flat roof barely reached a decade, now 20 years' duration is easily exceeded. Moreover, whilst in the past failures were mainly due to the quality of materials and to design errors, now failures are mainly attributable to design errors and poor quality of labour.

In this report, the author intends to describe, also by means of an ample case overview, how this process of innovation and improvement of the potential quality of the waterproofing systems has been developed, starting from the knowledge derived from the study of mistakes and of the mechanisms that trigger pathological situations.

Temperature [illegible] construction process(	Cyclic expansion, contraction	Contraction prevented by perimeter constraints	Cyclic tensile stresses in correspondence of lines [illegible]	Cracks, breaks
		Contraction prevented by reciprocal binding layers	Cyclic tensile stresses in correspondence of joints between insulation boards	Waterproofing corrugations, cracks
	Mechanical behaviour variation versus temperature changes	Contraction prevented by reciprocal binding layers	Lamellar stresses between waterproofing and underlying layer	Waterproofing corrugations, delamination and wind uplift, [illegible]
		Waterproofing cyclic stiffness, brittleness at low temperatures	Increase of tensile stresses during temperature lowering	Cracks, perforations, punching holes, detachments
		Waterproofing cyclic softening at high temperatures	[illegible]	Punching hole
		Permanent [illegible]	Permanent tensile stresses	Cracks, [illegible], lap joints, detachment, delamination and wind uplift
	[illegible] oxidation	[illegible], [illegible]	Tensile stress concentration	Cracks, perforations, punching holes, detachments
		[illegible], delamination of surface treatment, chalking, cracks	Temperature increase under solar radiation	[illegible]
	Water [illegible] condensation	Water evaporation	Blistering	[illegible] delamination, perforation, lap joints detachments

Figure 70 – Fault tree scheme extracted from UNI 9307-1-1988 Standard. "Flat roof. Design instructions. Waterproofing membrane": Thermal aging factors and pathological consequences

4.5.2 PATHOLOGIES AND BITUMEN BASED MEMBRANE INNOVATION

Until the 1960s, waterproofing systems were made on site by alternating coats of oxidized bituen and reinforcements in felt paper impregnated with bitumen. In general only two or three reinforcements were utilized and three or four bitumen coats of 1 kg/m^2. This was a traditional solution that in the past had replaced natural asphalt taken in Italy from quarries of asphaltic stone. This multi-layer solution made on site (built up roof), due to the stability of the cement based screed support, did not show major problems, but aged relatively quickly.

In the 1960s prefabricated membranes in oxidized bitumen were marketed; they were torch-applied membranes, initially reinforced with glass fibre felts. The great success of this solution, which usually comprised a double membrane glued by torch, was due to the more cost-effective and easier laying and to the removal of the need to take boilers to the building site to melt bitumen. Actually, such ease was only apparent and took its toll in terms of diffused failures: blistering, splitting, ridging, cracking, puncturing, membrane slippage, alligatoring, delamination, and punctioning (figure 71 to figure 76).

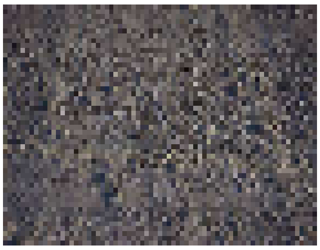

Figure 71 – Blistering

Figure 72 – Printability

Figure 73 – low puncturing resistance

Figure 74 – Alligatoring

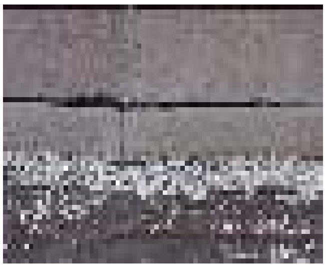

Figure 75 – Shrinkage by paper felts water absorption

Figure 76 – Membrane cracking on insulating panels joints

Besides the insufficient features typical of these membranes and also the laying by very low proficiency craftsmanship, the majority of pathologies particularly depended on the fact that attention to energy issues led to the marketing of insulation systems with polystyrene, polyurethane and mineral wool panels. Therefore, waterproofing membranes were no longer placed onto solid continuous and stable supports, but on discontinuous systems in panels with lower mechanical strengths and higher instability and thermal mobility. The consequence was a marked spreading of cracking pathologies (Figure 76). These failures derived from the lack of analysis of tensile ratios that were established between membrane and support, due to Movements between layers of different materials but also because of the increased thermal stress, before more relieved by the thermal inertia of screed cement supports.

Usually bituminous prefabricated membranes were laid in two layers (3 ÷ 4 kg/m^2) with the upper layer provided with a mineral surfacing or a metal facing. These systems featured low tensile properties, high thermal sensitivity and therefore fragility at low temperature and softening at summer operating temperatures. As to heat sensitivity, consequences implied slippage and "reptation" phenomena due to the cycle of shadows, which generated softening, and stiffening and therefore migration and corrugations (reputation, figure 77).

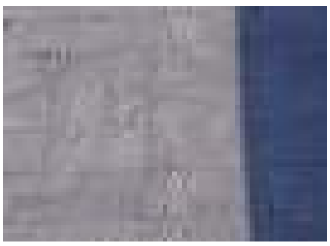

Figure 77 – Corrugation by thermal reptation (bitumen heat sensitivity)

Figure 78 – Slipping phenomena on slopes

Figure 79 – Joint splitting derived from slipping"

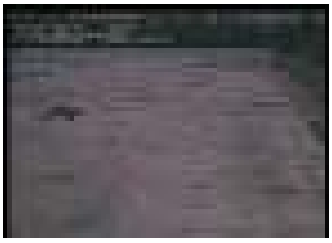

Figure 80 – Membrane splitting caused by HVAC. The structure in concrete prefab slab was air permeable

Figure 81 – The under pressure caused impressive cracks

Figure 82 – The cement aerated screed, bitumen glued to the membrane was completely fragmented

Figure 83 – Cracks parallel to the sheets laid with the same orientation

Figure 84 – The cracks were in correspondence of insulation continuous joints

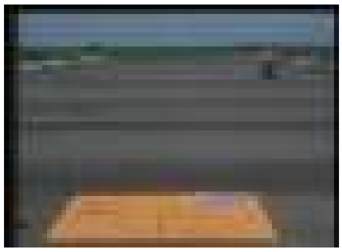

Figure 85 – After each intervention the phenomena iteratively occurred again

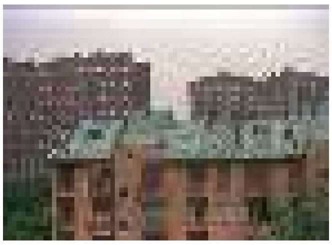

Figure 86 – Metal facing slippage

Figure 87 – Blistering caused by permeable overlaps

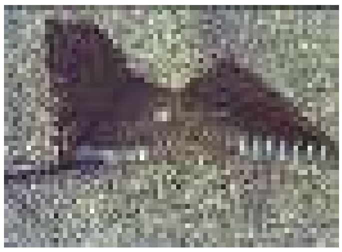

Figure 88 – Seams with "non stick" strip not burned during application

Similarly widespread was shrinkage of membranes (due to water absorption by paper felts), which generated tensions and dislocations on the perimeter (Figure 75). Furthermore, the introduction of insulating lighter foamed concrete screeds led to other flat roofs pathologies such as wind uplift, linked to their fragility and low mechanical strength (figure 80 to figure 82).

As observed before, an improvement in the quality of waterproofing membranes, in terms of better thermal stability, was achieved with the reinforcing of the membrane with glass fibre felts. Because of a higher tensile strength along the length of the sheet it was recommended that the two membranes were laid with the sheets laid crosswise. In many cases sheets were laid with the same orientation, hence there was a mechanical anisotropy in the double layer. Thus, due to this anisotropy, parallel cracking occurred in correspondence of continuous thermal panels joints (figure 83 to figure 85).

After each local intervention (sheet adhered by bitumen over the crack) the phenomena iteratively occurred again, because the tensional causes were not eliminated. Slippage and detachment of metal facing was another rather widespread pathology (figure 86).

Figure 89 – Wind displacement of double layer bitumen glass fiber reinforced membrane

Figure 90 – The crack morphology evidence the fragility of the membrane

Figure 91 – Large amount of bitumen but incomplete attach of the insulation panels

Figure 92 – A flat roof with an area of 200.000 square meters

Figure 93 – Diffused cracks near skylights

Figure 94 – No bitumen between mineral wool panels and membrane

Except in the case of foamed concrete screed and apart from the above case of cracking, membrane fully adhered to insulation panels was a good and generally used standard procedure of laying and this ensured a good wind resistance of flat roof systems.

Some problems were noticed in roofs with steel deck. In the example shown in figure 89 to figure 91, in spite of the abundant coating with bitumen, the concave shape of the sheet metal did not ensure a complete and safe attach (yellow strips) of the insulation panels with respect to the action of the wind.

Figure 92 to figure 94 show another case of wind dislocation. In this case, the waterproofing membrane (double layer, glass fiber reinforced oxidized bitumen membrane) was only fastened by perimeter attach to roof skylights. The insulation in mineral fibre panels, contrary the good practice, was not connected with bitumen to the prefabricated concrete slabs and as a result there was a diffused cracking phenomena in correspondence of skylight fixed points.

The introduction of polyurethane insulating panels led to the emergence of other pathologies resulting from the mode of panel production (figure 95 to figure 97). After letting polyurethane foam in a box, panels were cut with the desired thickness. This procedure led to non-homogeneous expansions. After cutting, this situation led to marked warping and cracks.

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Figure 95 – Flat roof with old built-up roof membrane. Membrane warping appeared despite the presence of a gravel layer

Figure 96 – Membrane warping affected after gravel removal

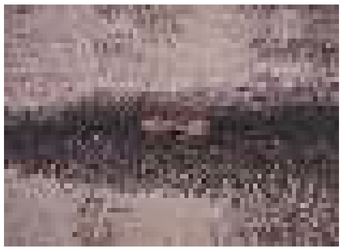

Figure 97 – Cracks and alligatoring

Figure 98 – A flat roof with bitumen polymer, fiber glass felt reinforced, mono-ply membrane of a gravel layer

Figure 99 – Delaminating between insulation panels and membrane

Figure 100 – Also polyurethane panels were not efficiently connected with the concrete slab

These instabilities were subsequently managed by means of different production processes and in particular by treating panels with finishing layers, whose function was geometrical stabilization and to make membrane gluing easier. In more recent years membranes made of distilled bitumen modified with atactic polypropylene, were marketed. These membranes were originally produced and marketed in Italy in the middle 1960s and reached large diffusion when export in the US too began. Also SBS bitumen modified membrane was introduced on the market particularly in colder climates. The use of modified bitumen torched in place membrane made a clear quality leap possible with respect to the compound, characterized by a lower thermal sensitivity. In particular, with respect to previous materials, an increase in the softening point, an increase in viscosity, an improvement in cold flexibility and a higher duration were observed. Also in this case wind uplift pathologies were observed in application on prefabricated concrete industrial decks.

Figure 98 to figure 100 show a case of dislocation of an APP bitumen modified glass fibre reinforced membrane. The wind uplifting was caused by the impossibility to glue polyurethane panels to the structural support, since the surface of the prefabricated concrete deck was irregular. In the pictures we can observe that the break of a low quality APP bitumen membrane reinforced with mineral felts is still of the fragile type.

A further improvement in the qualities of polymer bitumen membranes was achieved with polyester fibre reinforcing layers, sometime composed with woven glass fibre, which improved mechanical performances. Also bitumen modification has been gradually improved with ad hoc produced polyolefin, now with excellent cold flexibility.

Figure 101 – The membrane inflated by negative pressure during a storm, The site is characterized by high windiness

Figure 102 – Erroneous dislocation of mechanical fasteners, activated delaminating in the thickness of the mineral wood panel

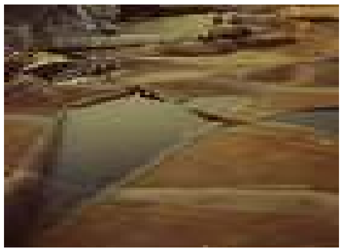

Figure 103 – The excellent flexibility of the APP bitumen membrane avoided water infiltration except in perimeter area

Figure 104 – Linear corrugation caused by wind uplift

Figure 105 – The two layer of the membrane are not welded

Figure 106 – The membrane is not welded to the perlite panels. Panels was lifted by the wind: see the difference of levels

Improvement of rheological behaviour is also observed: see by comparison with the previous case figure 101 to figure 103 showing the wind damages to a roof made with APP polymer bitumen membranes reinforced with unwoven polyester fibre mat.The membrane was inflated by the wind suction, but it did not show a fragile behaviour as in the previous case and was simply dislocated. Infiltrations were only present on the roof perimeter, where the waterproofing membrane was torn down and removed from the roof hatch flashing.

Figure 104 to figure 106 show another case of wind dislocation. In this case, the waterproofing membrane was only fastened by roof skylights perimeter. As can be observed in the figures, the two layers of the membrane and the insulation panels, erroneously, were not welded together Therefore there appears a corrugation at the continuous joint lines between expanded perlite panels.

Other wind uplift membrane is shown in figure 107 to figure 109 with different corrugation geometry and with active water infiltrations.

Figure 107 – See the typical corrugation in the angle of the flat roof

Figure 108 – In this case seams were disassembled

Figure 109 – Another case of wind uplift

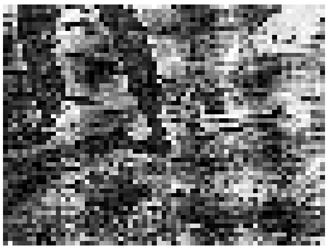

Figure 110 – Mono-ply APP membrane. In correspondence of a slab level difference the membrane is in tension

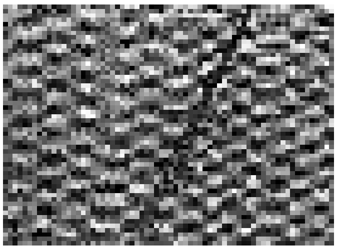

Figure 111 – The "production memory shrinkage" caused seams detachment

Figure 112 – Perpendicular ridgings caused by reptation. The two layer of the membrane are crossway installed

The use of NT polyester membrane reinforcements has constantly increased especially for a better resistance to fatigue accompanied by good mechanical features (tensile, elongation and tearing strength).

A factor that must however be kept into account is the fact that polyester is an organic material and is therefore sensitive to high temperatures. Furthermore during the membrane production phases (high temperatures and mechanical stress in the production line) the sheet can be stretched longitudinally (from minimum *0.5% to 1.5 %)* generating tensions within the reinforcement that remain blocked by the subsequent rapid cooling of the membrane.

Once the membrane has been laid in site, the "production memory" can cause contractions of the membrane on the roof due to the fact that polyester (no longer kept by the high viscosity of the mixture since it is overheated by the action of the sun) tends to take again the dimension that it had before it passed to the membrane production line (figure 110 to figure 112). This event of contraction with high summer temperature particularly occurs in the first year of exposure, but can be controlled by better production procedure (figure 113 to figure 115).

Thermal instability events are at the base of the "reptation" phenomenon, which is nowadays a rather common pathology in double layer membrane when not fully connected by torch. Figure 77 shows an example of "reptation" due to expansions and contractions of the polyester reinforced membranes. In this case notice the crossed shapes of corrugations, due to the perpendicular lying of the two sheets. This instability phenomenon can be counteracted by putting maximum attention in the membrane production stage and by taking in situ certain actions, like a perfect welding of the membranes during application in roof.

In the past, in order to reduce dimensional instability, a membrane was very successfully introduced in the market with a double reinforcement: polyester and fibre glass mats. The use of two distinct reinforcements in fact allowed an optimal bitumen impregnation. Now composite reinforcements are currently introduced in the marketplace, with the advantage of the elimination of the typical rigidity of that membranes and a more uniform stability of the membrane.

Composite reinforcement (better called stabilized reinforcements) is generally made up of polyester TNT in which glass nets or longitudinal yarns are included during production. Composite reinforcement tends to minimize tensile elongation of polyester NT during the production of the membrane and to give more dimensional thermal in situ stability. This type of membrane is used particularly for special single–layers roofs applied mechanically fastened.

These applications require materials with high dimensional stability since membranes are not torch applied to the support and are subject to the external thermal actions. In this case the membrane during the application stage it is not subject to the so-called "pre-relaxation" (typical in hot applications) that can contribute to reduce contraction in place.

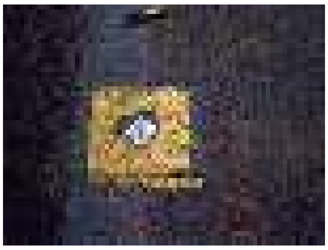

Figure 113 – Puncturing by mechanical fasteners

Figure 114 – Fishmouths.

Figure 115 – Blister

4.5.3 PATHOLOGIES AND SYNTHETIC MEMBRANES INNOVATION

Also the history of applications of synthetic membranes as waterproofing systems is accompanied by sensational failures, though there are fewer types of pathologies.

The application of synthetic membranes dates back to the 1950-60s. As to Italy, the introduced materials were PVC, polyisobuthylene, chlorinated sulphonate polyethylene. As to polyisobuthylene, its application was traditional, since it was compatible with the melting bitumen welding.

Some of these pathologies were connected to the inappropriateness of this hot treatment, but others were dependent on their being rigidly glued to insulating panels characterized by marked shrinkage and thermal movements.

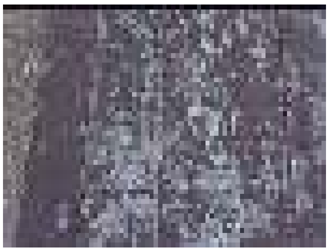

Figure 116 – Cracks in Poly - isobutilene membrane laid on extruded polystyrene panels

Figure 117 – The cracks appeared after a thermal choc caused by a summer rain. They was situated just next each joint between panels

Figure 118 – The restoration with a new poly-isobutylene membrane, just laid on the old one, without a separation layer, was ineffective. New cracks appeared

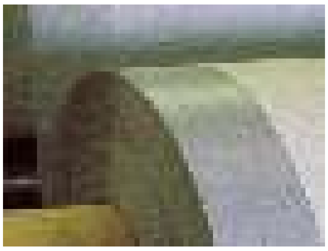

Figure 119 – Chlorosul-phonated polyethylene membrane, pre-coupled with a separation layer in paper felt

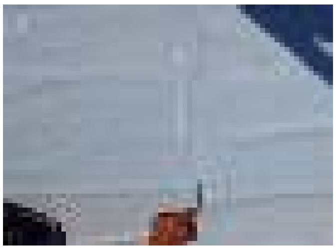

Figure 120 – Cracks on "selvedge"

Figure 121 – The localization of services like UTA can be the cause of much trouble

This is the case presented in figure 116 to figure 118 where, in correspondence with the joints between panels, cracks quickly formed on membranes, immediately after the laying, as a consequence of thermal shocks such as storms in summer days. In this case insulating panels were made of extruded polystyrene with high mechanical strength and most probably had not been subject to post-production contraction yet.

Another material introduced in those years was the chlorosulphonated polyethylene. Traditionally, the sheets were equipped on the lower side with an asbestos felt as separation layer or to make laying with total bitumen welding possible. When the use of asbestos was prohibited, in more recent years, people tried to replace it with paper based sheets with high tensile strength. The result of these first applications was the formation almost immediately after laying of lesions in correspondence of the joints where the paper layer was interrupted (figure 119 to figure 121).

But the history of PVC is maybe more interesting since its first introduction was accompanied by the intense spreading of failures due to membrane shrinkage. The PVC is very hard and must be plasticized to be suitable for roofing. The problem with the early PVC membrane was that the plasticizer was fugitive and tended to migrate outside upon exposure The loss of plasticizer caused shrinkage, loss of volume, brittleness. Another event that was a source of early ageing was poor UV resistance. Subsequently the problem was solved by means of the introduction in the mix of inorganic powders that blocked UV penetration.

Figure 122 – Shrinkage of PVC membrane was the cause of many infiltrations

Figure 123 – In this case the reduction of length of the membrane cause important infiltration

Figure 124 – Corrugation activated by PVC shrinkage

Figure 125 – PVC membrane tensioned on the roof perimeter was punctured by hail

Figure 126 – Hail puncture

Figure 127 – PVC membrane under shrinkage tension

The first production technique of PVC membranes was by calendaring. The "memory" of tensile actions developed by manufacturing technique generated, immediately after application, longitudinal shrinkage that was added to the shrinkage activated by plasticizer migration (figure 122 to figure 124).

At the time many repairs were made by adding new 20-30 cm PVC strips onto the perimeter in the areas that remained uncovered because of the shrinkage of PVC membranes. These pathologies led membrane manufacturers to develop new production modes.

From calendaring production systems the next step was the vertical extrusion. This latter system cancelled or made less serious the issue of "memory" contraction; in this the contraction was transversal. To reduce shrinkages were PVC membranes produced with mineral fibre dispersed in the compound.

A pathology connected to losses of flexibility for early ageing (due to migration of plasticizer) and to the traction on the perimeter, was the break because of hail punching the membrane. An example of this can be seen in figure 125 to figure 127.

Laboratory tests ascertained that contraction by aging development was accelerated by direct contact with polystyrene panels in the presence of temperatures above 25°C. This occurred in the case presented in figure 58. To reduce this phenomena was generalised the adoption of separation felts.

As to the issue of contraction from aging, besides mix improvements, a new production technology by coating machine was introduced. This technique allowed inserting in the membrane reinforcement in glass veil (50 g/m^2). Moreover, for systems fully anchored by adhesive, PVC membranes are currently in production equipped with NT polyester felt on the lower side.

In conclusion, it can be said that PVC technology has now reached a significant potential duration. It should not be forgotten, however, that these materials require careful design choices, the execution by specialist firms and particularly skilled labour. In particular, mechanical fixing along internal and external perimeters proves to be fundamental.

Figure 128 – PVC membrane aging accelerated by direct contact with polystyrene panels

Figure 129 – Villain use of PVC membrane with different welding temperature

Figure 130 – The sheets can be detached manually

Figure 131 – High thickness of insulation panels can cause puncturing by unfit mechanical fasteners

Figure 132 – The localisation of mechanical fastener is correct

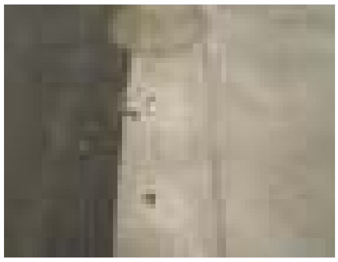

Figure 133 – But the head of the nail is too high. The deformation of the insulation panel under the charge causes the perforation of the membrane.

A skilled labour is always necessary. In the case presented in figure 129 and figure 130 the use of two PVCs of different origin, and therefore with different welding temperature, generates joints between the sheets that can be detached manually. The hostile approach with respect to the use of PVC led to the development of new materials that take the generic name of flexible polyolefins.

This is a family of "intrinsic" flexibility materials, which is not resulting from the action of plasticizing oils as is the case of PVC. There follows a higher resistance to aging.

There are two flexible thermoplastic polyolefin families (FPO), polypropylene based and polyethylene based. For roof application the base should fundamentally be polypropylene. Generally they are reinforced with glass fabrics integrated sometime with NT synthetic grid.

The particular production technology makes it possible to produce membranes with several layers of different features. FPO membranes are bitumen and EPS compatible. Current knowledge suggests using FPO manufactured by major manufacturer.

The problems to be encountered fundamentally deal with the modes of laying and gluing seams (which requires skilled labour) and other problems that deal with roof design (such as resistance to wind) and detail issues typical of synthetic membranes.

A common pathology for synthetic membrane, in the case of high thickness of insulation panels (with high deformability under charge), required by energy-oriented laws, is caused by use of incorrect fasteners that can pierce the membrane.

The deformability under charge of the insulation panels can activate the piercing of the membrane along maintenance pathways for service equipment areas, which are increasingly placed on the roof (figure 131 to figure 133).

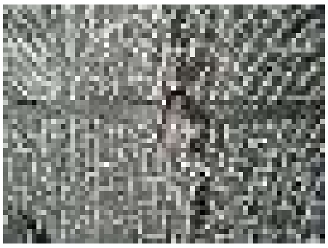

Figure 134 – MModified SBS bitumen membrane supported on HDPE sheets self-adhering

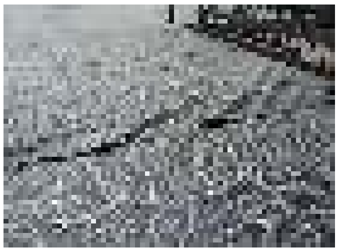

Figure 135 – Tensions activated by incorrect application of the membrane

We conclude this overview with an example that shows how a seemingly simple new solution, with not sufficient application experience, lead to surprisingly negative results. This is the case presented in Figure 134 and figure 135 regarding self-adhesive membranes (modified SBS bitumen membrane supported on HDPE sheets self-adhering), which are becoming increasingly common in the marketplace. In the figures you can see the disastrous situation the day after the installation. The incorrect application methodology induced differential tension between the two sides of the membrane, which was relaxed by deformations.

4.5.4 CONCLUSIONS

In recent years, the sector of flat roofs in Italy and Europe has developed actions which are potentially able to activate a qualitatively mature market, and able to ensure the reliability level required to a subsystem in the building sector, the flat roof, which has primary functional significance.

Table 14 presents the European flat roofing market (in 2004) in millions of square metres. Table 15 presents the USA flat roofing (new construction) sales percentage in 2001.

In a strategic subsystem which has the primary function to protect inner rooms from rainwater and to ensure liveability, the improvement in manufacturing processes and the regulatory framework regarding waterproofing products, which has been developed over the years, would make possible the production of extremely reliable waterproofing systems, with a conventional life expectancy of around or even more than twenty years.

The most active manufacturing firms of waterproofing membranes, also with respect to new laws which define new responsibilities for them with respect to the eligibility to the use of products, have made paper and electronic technical documents available to designers in order to deal with the issue of product selection criteria, definition of details and laying rules. While this technical context is objectively positive, the reality induces pessimistic remarks, since the sector is still affected by a consistent presence of pathologies.

Designers must take considerable blame since they tend to fulfil their obligations in a formal, quick and unsubstantial way, with insufficient and often fanciful graphic and specification systems, often collated from different sources, which are not necessarily consistent, often without any reference to the specific design situations. Often the *cut and paste approach* made possible by electronic means of communication (the Internet and CDs) leads to the creation of specifications which in musical terms would be defined as a mix, with an effect which is not always pleasant, as to their results for the end users.

Often people rely excessively on the excellence of the membranes utilized, forgetting that even the best membrane cannot ensure in itself the quality of the roof system. This quality depends actually on the perfect functional combining of all the relevant layers and on the development of correct details. The best membrane cannot make up for design mistakes and laying errors and cannot avoid the development of pathologies by its own.

Designers' responsibilities are accompanied by those of clients, of manufacturing firms and of laying firms that often consider minimum price as the only criterion of reference for transactions, but also by a lack of professional behaviour that does not favour the achievement of quality standards in line with the potential results mentioned before.

Of course, much depends also on the presence in the marketplace of inexperienced firms (often only provided with the "welding torch culture"), that are not provided with the technical knowledge that allows them not only to work at best with respect to the operational quality of the jobs assigned to them, but also to assess the reliability of the roofing systems within the overall structure.

In conclusion, we must unfortunately remark that while the study of pathologies is a tool for knowledge and a stimulus to the development of more reliable materials, solutions and manufacturing organizations, new technologies often trigger new modes for the development of pathological cases.

4.5.5 REFERENCES

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Table 14 - The European flat roofing market (in 2004) in millions of square metres

	EPDM	*SBS APP*	*SBS Polymer-modified bitumen*	*APP Polymer-modified bitumen*	*PVC*	*TPO*
	Single ply	*Double ply*	*Single ply*	*Single ply*	*Single ply*	*Single ply*
Europe	9.35	15. 79	135.8	97.44	47.5	58.57

Table 15 - The USA flat roofing (new construction) sales percentage in 2001

	EPDM [%]	*BUR* [%]	*SBS Polymer-modified bitumen* [%]	*APP Polymer-modified bitume* [%]*n*	*PVC* [%]	*TPO*
	Single ply	*Multi layer*	*Single ply*	*Single ply*	*Single ply*	*Single ply*
USA	27.9	12.3	10.6	10.1	7.5	7.1

4.6 RISING DAMP PATHOLOGY DIAGNOSIS AND TREATMENT

(Vasco Peixoto de Freitas, Ana Sofia Guimarães and Isabel Torres)

4.6.1 THE PROBLEM

Rising damp is one of the main causes of deterioration in old buildings and historic monuments (figure 136).

Figure 136 - Rising Damp

Old buildings with rising damp pathologies require the appropriate solution to eliminate this problem. The treatment methods most commonly used today are:

- Installation of moisture barrier
  - Physical barriers
  - Chemical barriers
  - Air space
- Disguising anomalies
  - Renderings with controlled porometry and porosity
  - Inner cladding separated by an air space
- Electro-osmosis
- Knappen tubes
- Wall base ventilation

As these solutions may not be completely effective, it is necessary to calculate each one's chances of success, along with the difficulties and cost of applying it.

4.6.2 TREATMENT METHODS

4.6.2.1 INSTALLATION OF MOISTURE BARRIER

Physical barrier: Partial replacement of masonry (A1)

This involves replacing parts of the masonry with impermeable materials. The first step is to demolish the masonry in small stretches (of around 50 cm) throughout the whole thickness of the wall. This is then replaced with impermeable materials.

This method is effective, but it is difficult and time-consuming, and can only be used for walls made of small regular blocks (figure 137 - A1).

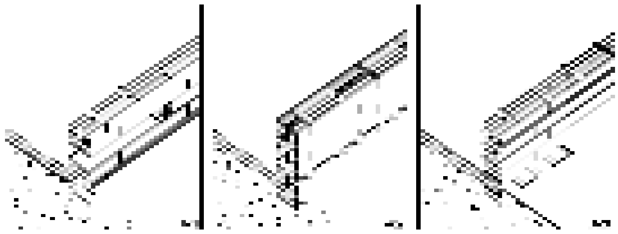


Figure 137 - Replacement of parts of the masonry with impermeable physical barrier

All gaps and spaces must be properly filled after the application of the watertight material. In very thick walls, slots may be created on both sides of the wall with helicoidal wire.

These methods have the drawbacks that they produce vibrations and may result in instability.

Physical barrier: Massari's method (A2)

Massari's method involves drilling a series of holes in 45-50 cm stretches of wall. First, a series of holes are drilled that are tangential to one other. Then a second series is drilled with their centres at the previous points of tangency (figure 137 - A2). After the holes have been drilled, they are cleaned and filled with mortar made of synthetic binders. The mortar must be left to harden, before proceeding to the next stretch.

Physical barrier: Schöner-Turn method (A3)

This technique involves placing corrugated stainless steel plates in the walls to be treated, using jackhammers (figure 137 - A3). This method can only be used with masonry consisting of regular blocks, such as bricks or ashlar, with continuous and well-defined horizontal joins.

The technique is limited by the vibrations caused by the jackhammers.

Chemical Barrier

The appearance of new synthetic materials has enabled chemical barriers to be inserted (through diffusion or injection) into the porous structures of the materials of the walls.

These barriers should be located as near to the ground as possible. To insert the products, holes are made along the wall at intervals of 10 cm to 20 cm to a depth of approximately 1/3 of the wall thickness. If only one side is perforated, the depth should be 2/3 of the wall thickness (figure 138).

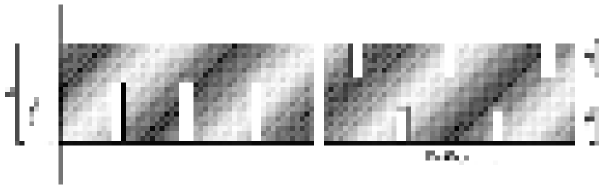


Figure 138 - Hole drilling principle

After the holes have been drilled the products can be introduced using one of the following techniques:

Diffusion – Gravity is used to diffuse the product throughout the porous structures. The holes may be horizontal or sloping downwards. Tubes attached to bottles containing the selected product are inserted into these holes (figure 139, left);

Injection – In this case, the product is introduced into the wall with the aid of pressure equipment, which is directly connected to the tubes inserted into the holes. The pressure used varies in accordance with the porosity and mechanical resistance of the material, though should not normally exceed 0.4 MPa. When the chemicals are injected at high pressure, it helps expel the air from the pores, facilitating the penetration and homogeneous distribution of the product (figure 139, right).

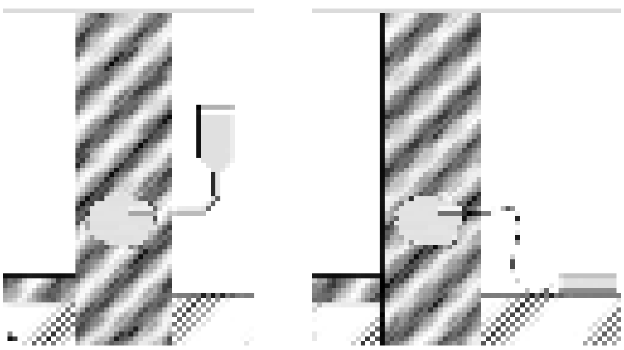


Figure 139 - Introduction through diffusion and injection

For the chemical barrier to work, it must penetrate well and continuously. However, not all products are suitable for all wall types, so the most appropriate product and form of application should be chosen for each case.

Insertion of air space

This technique consists of reducing the absorbent section by replacing part of the material with an air space. This allows the absorbed water to evaporate more easily through the openings, and it reduces the amount of water absorbed. It uses air as a treatment principle, although differently from its use in a wall base ventilation system (see below), where the air circulates inside the system and activates evaporation.

Although it is an interesting idea, the technique is rarely used for architectural and structural reasons. It is particularly difficult to apply to buildings with very thick walls.

4.6.2.2 DISGUISING ANOMALIES

Renderings with controlled porometry and porosity

When it is not feasible to treat the underlying causes of rising damp an alternative is to place porous materials on the outside of the wall (with controlled porosity and porometry) so as to facilitate surface evaporation and salt crystallization without causing deterioration. Renderings with different undercoats may be used, so that porosity decreases from the outside in (figure 140). Salt crystallization occurs without harming the porous structure, but it may lead to the appearance of efflorescence.

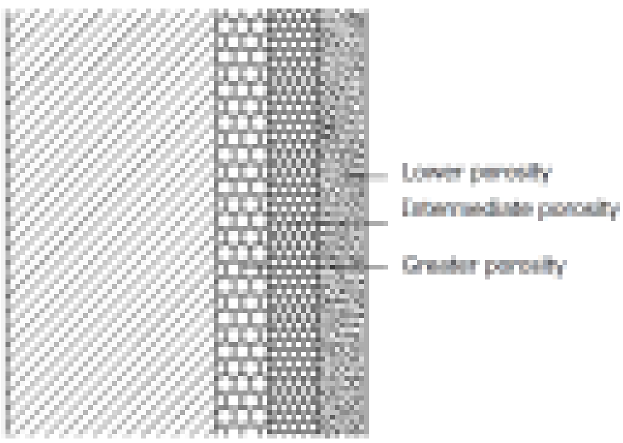


Figure 140 - Rendering with controlled porosity and porometry

Inner cladding separated by an air space

This method does not treat the causes of the problem but rather aims to disguise it. It involves placing a thin layer of cladding on the inside, some 10 cm from the wall, so that there is no physical point of contact. The air space between the wall and the cladding should be ventilated to the exterior through orifices at different levels. The base of the wall should be impermeable so that there is no moisture continuity (figure 141). It is not advisable for the air space ventilation to be directed towards the inside of the building.

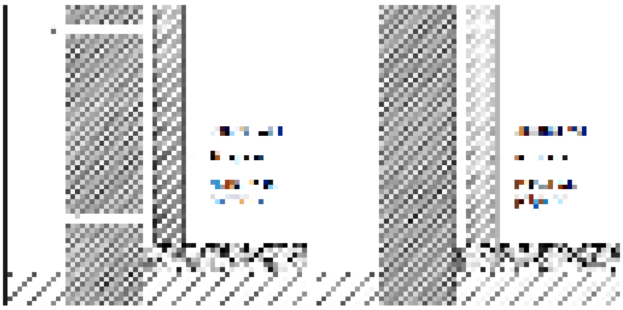


Figure 141 - Interior cladding

This technique has several drawbacks, including the fact that it reduces the usable area, hides the original wall and requires the adjustment of any mechanisms placed on the wall.

4.6.2.3 ELECTROOSMOSIS

Electro-osmotic systems generate an electric potential that counteracts capillary action. Active, semi-passive and passive techniques may be used, though none are very effective. They are thus of limited interest for historical monuments.

4.6.2.4 KNAPPEN TUBES

The Knappen method consists of inserting tubes that facilitate the ventilation and/or drying process and reduce capillary potential.

As this system is relatively cheap it has been widely used, though with little success. Not only is it of limited effectiveness, it is not very aesthetic and so it is unsuitable for use on historical buildings.

4.6.2.5 WALL BASE VENTILATION

Many of the techniques described above have not proved very effective in treating the thick walls of heterogeneous composition that are often found in historic monuments and other old buildings.

The Laboratory of Building Physics (LFC) at the Faculty of Engineering, University of Porto (FEUP) has been engaged in experimental research designed to test the effectiveness of a technique for treating rising damp that consists of ventilating the base of walls using either natural ventilation (Figs 142, left, and 143) or a hygro-regulable mechanical device (Fig. 142, right). The aim is to increase evaporation through the construction of ventilated side channels. This technique should be used when the wall foundations are located above the groundwater level.

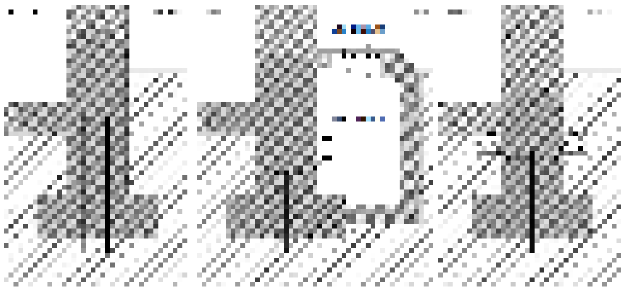


Figure 142 - Wall base ventilation system: functioning principle

The external channels should have a gutter to collect and draw off the rainwater, and upper waterproofing and ventilation. The channel should be placed at a depth that ensures structural stability. On the inside, the ventilation system should consist of channels attached to a mechanical hygro-regulator ventilation device.

Figure 143 – Natural wall base ventilation on the outside

4.6.2.6 ADVANTAGES AND DRAWBACKS OF THE TREATMENT METHODS

All the techniques described above for the treatment of rising damp have their advantages and drawbacks. The moisture barrier created by physical barriers generates vibrations that can cause stability problems; the introduction of waterproofing or filler products is ineffective when the walls are very thick and heterogeneous, as is usually the case with old buildings; renderings with controlled porosity and porometry have limitations that include the fact that they cannot be applied to unplastered walls; cladding, separated from the wall by an air space, would be effective if correctly applied, but it reduces the usable area and hides the original wall from view.

Wall base ventilation has great potential for the treatment of rising damp in old buildings. However, the ventilation must never under any circumstances be directed into the building.

4.6.3 VALIDATION OF THE WALL BASE VENTILATION TECHNOLOGY

4.6.3.1 EXPERIMENTAL STUDY

4.6.3.1.1 PHYSICAL MODEL

The aim of the experimental study was to assess how a wall base ventilation system affects the performance of stone walls with regard to rising damp.

The physical model chosen involved creating prismatic stone samples with a section of 1.58x2.00x0.20 m^3 (formed of 5 prismatic pieces of limestone measuring 0.30x2.00x0.20 m^3 alternating with lime mortar joints 1 cm thick), waterproofed on the two top surfaces so that was no moisture flow in that direction. Tubs measuring around 2.20x2.50x0.50 m^3 were built, designed to keep water levels constant during the test (figure 144).

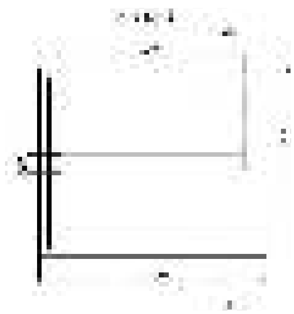
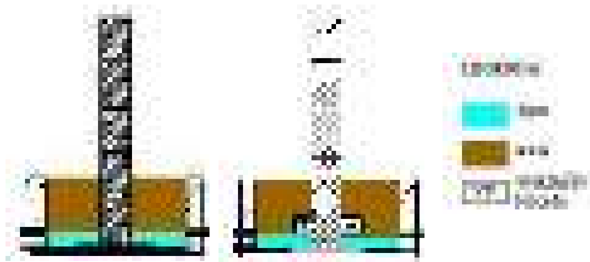


Figure 144 – Configuration of the tubs

Configurations 1 and 2 (figure 145) show the wall in contact with the ground without (1) and with (2) ventilation on both surfaces.

Configuration 1 Configuration 2



Introduction of sand on both sides of the wall | Introduction of forced ventilation system

Figure 145 – Experiment configuration

In Configuration 1, both surfaces of the wall are buried in sand to a height of 45 cm from its base. In Configuration 2, the aim was to assess the effect of a wall base ventilation system, so a ventilation device was placed on either side of the wall (figure 145). This consisted of a wooden box (20x30 cm) placed 15 cm from the base of the wall along its whole length, with two openings to which were attached flexible tubes to ventilate the box. A mechanical extractor was placed in one tube (figure 146), while the other was left free to allow the uninterrupted entry of air. The extraction system functioned continuously to ensure that the temperature and relative humidity conditions inside the ventilation system were identical to those in the laboratory.

Figure 146 – Wall base ventilation device

Probes were used to obtain readings of the temperature and relative humidity inside the walls at different heights and depths. Given the symmetry of the system, the probes were placed in the central section (at a depth of 10 cm) and also at 5 cm. All the probes were connected to a recording and data acquisition system. The atmospheric conditions in the laboratory (relative humidity and temperature) were also recorded throughout the duration of the experiment.

4.6.3.1.2 EXPERIMENTAL VALIDATION

The variation in relative humidity at a particular level enabled us to determine the moment when the rising damp front, generated by capillary action, reached the level of the sensors. Figure 147 shows the position of the sensors. Type B sensors were located in the middle of the wall thickness, while Type A ones are located 5 cm from the surface. Level 9 corresponds to the third row of stones 61.5 cm from the base.

The laboratory tests showed that, for Configuration 1 (i.e. without the wall base ventilation system), the sensors recorded 100% humidity after a given period of time, which means that the damp front had reached that level. On the other hand, in Configuration 2 (with the ventilation system installed), the relative humidity remained constant and less than 70%, even after a longer period of time, since there was no rising damp (figure 147).

This shows that the wall base ventilation system is effective in reducing the maximum level reached by water in its liquid state.

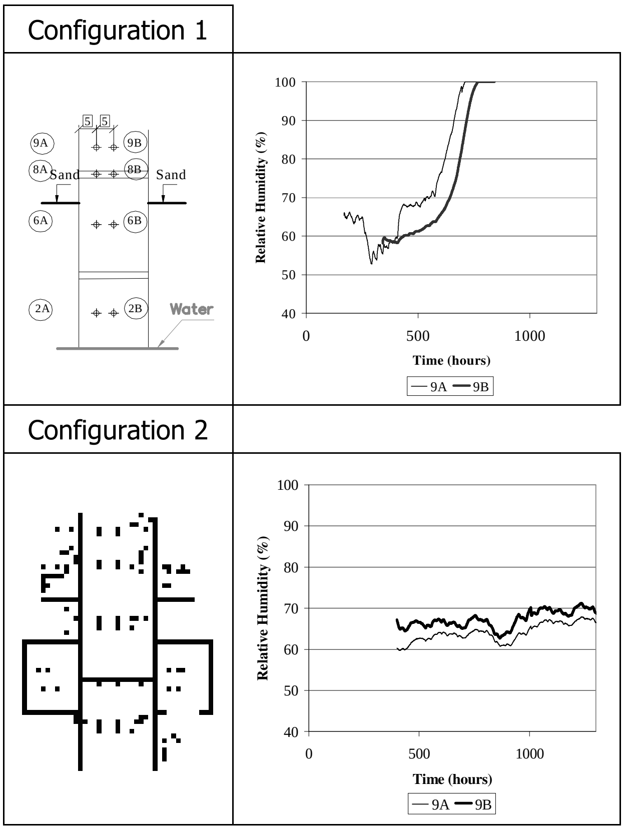


Figure 147 – Results obtained for Configurations 1 and 2 at Level 9

4.6.3.2 NUMERICAL VALIDATION

Simulations were performed to compare the experimental and numerical results, using the programme WUFI 2D, designed by the Fraunfofer Institute of Building Physics. This performed a 2D analysis of heat and moisture transfer between building materials [4].

In the simulations, the properties of the materials, determined experimentally in the Building Physics Laboratory, were introduced, as well as the specific boundary conditions of each situation, the recorded climate conditions and the real duration of each test (different for each configuration).

Figure 148 presents the results for Configurations 1 and 2, showing that the level of rising damp was lower in Configuration 2.

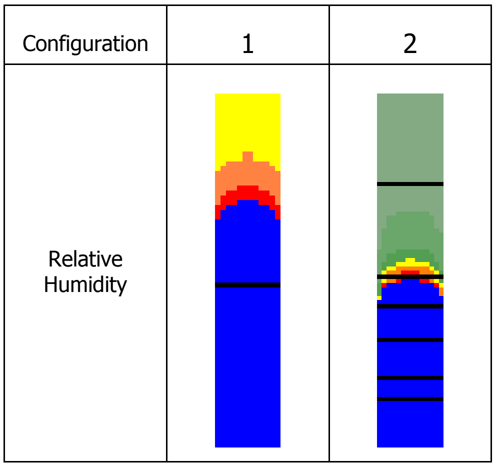


Figure 148 – Variation in relative damp in the cross section after 1 year

When the results of the experiments were compared with the simulations, some differences were found.

In the first rows of stones there were no significant differences between the results for either configuration, which meant that the programme was validated both qualitatively and quantitatively.

However, higher up the wall, the simulations showed a slight delay in the advance of the damp front in relation to the experimental study. This might indicate the influence of the interface between them. Whatever the continuity condition, the stone/mortar interface between layers affects the water absorption/drying kinetics of the building materials, causing the discrepancy between the experimental and numerical results. The behaviour of this interface requires further study.

In any case, wall base ventilation reduces the level achieved by the damp front.

4.6.3.3 *IN SITU* VALIDATION

4.6.3.3.1 HYGRO-REGULABLE VENTILATION SYSTEM

A hygro-regulable wall base ventilation system was installed in a church. Air was admitted through an opening to the outside and the exhaust was controlled by a hygro-regulable ventilation system (figure 149).

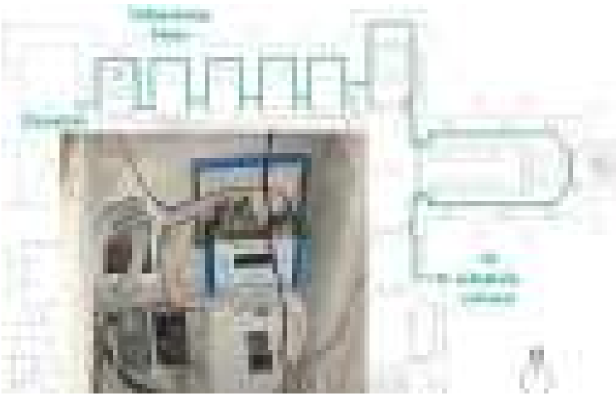


Figure 149 – Air intake and exhaust in the wall base ventilation system

The system was placed on the inner surface of the walls, immediately below the granite flagstones (figure 150).

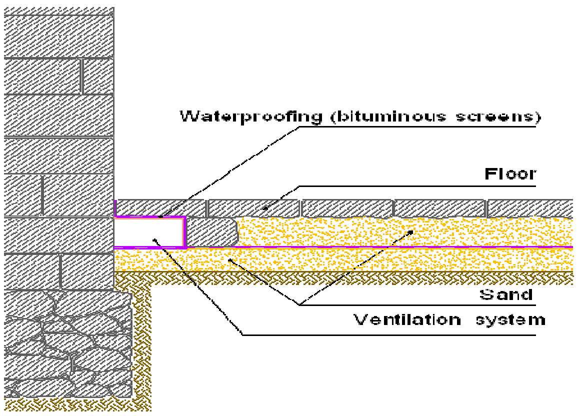


Figure 150 – Geometry of the wall base ventilation system

The ventilation system had two probes and two temperature and relative humidity transmitters, a control module and a data acquisition system for recording and operating the air extraction device.

One of the probes was placed near the outside and the other inside the ventilation tubing, next to the exhaust outlet. Both were connected to a temperature and relative humidity transmitter.

The data acquisition system stored the readings taken by the probes, enabling the effectiveness of the solution to be assessed.

The system recorded the relative humidity and temperature at the entrance and exit of the system, and operated the ventilator whenever the vapour pressure at the exit was higher than the vapour pressure at the entrance.

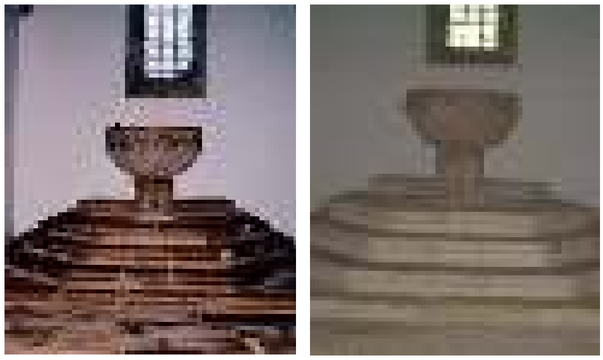


Figure 151 – Before and after the installation of the wall base ventilation system

4.6.3.3.2 FUNCTIONING CRITERIA: PREVENTING CONDENSATIONS

The ventilation device was connected for 52% of the time, in accordance with the functioning criteria described. For the other 48% of the time, it was switched off, in both summer and winter, as there was probably condensation within the system.

The system removed more water in summer than in winter (figure 152).

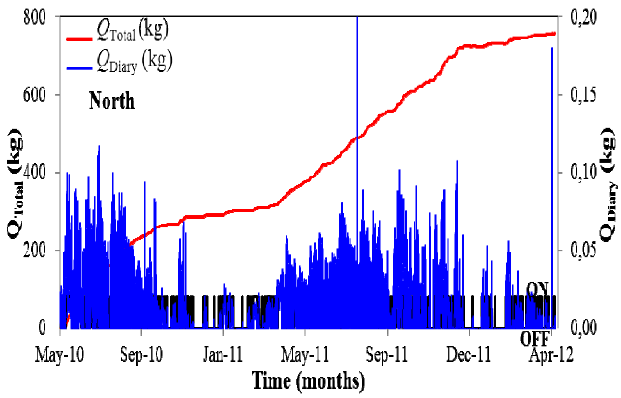


Figure 152 – Amount of water removed and accumulated by the ventilation system

4.6.4 CONCLUSIONS

There are many pathologies associated with rising damp. Different techniques are used to treat this problem, but none is very effective with historic buildings.

Wall base ventilation in association with a hygro-regulable system was validated experimentally, numerically and *in situ*, demonstrating its potential for use in historic buildings.

In practice, the systems need to be designed and sized, and for this, the research completed and work still under way at the Building Physics Laboratory (LFC) of the Faculty of Engineering, University of Porto (FEUP), is essential.

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4.7 RELATIONS AMONG PATHOLOGIES, BUILDING TECHNOLOGIES AND BUILDING TYPOLOGIES

(Francesco Marino)

4.7.1 INTRODUCTION

This study collects and analyzes the whole stock of interventions that the E.P.E.R. (*Provincial Bureau for Residential Building of Province of Potenza*, i.e. the old *Istituto Autonomo per le Case Popolari*) realized during the last century, in the Province of Potenza, with the aim of analyzing its contents according to a typological and technological point of view, considering use and aging state, the performance quality, functional anomalies or defects, situations of decay and recurrent pathologies.

Within a more complex research that, thanks to an organic analysis of the E.P.E.R. flat real estate, had the aim of producing a sort of reliable catalogue of pathologies and appropriate maintenance techniques in specific cases, an appropriate procedure to support the decisions made within the cataloguing process has been adopted, based on the analysis of single cases and the diagnosis of the decay process.

This system is based on the examination of much data and base knowledge that makes it possible to project interventions of maintenance and preservation of buildings. All this, linking the anomalies to causes of bad functioning and defects in buildings, as well as in techniques of realization or in maintenance actions.

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The main problem that the E.P.E.R. has to face at the moment is managing the interventions of maintenance and rehabilitation of a large number of buildings. Moreover, this is complicated by the variety of technologies and typologies of the more than 12.500 flats, built during a period of 90 years, in 101 municipalities of the Province of Potenza.

4.7.2 THE E.P.E.R IN THE PROVINCE OF POTENZA

A first step in the research was dedicated to acquiring detailed information on the flat real estate, object of the analysis, to quantify buildings and flats, define their exact location and localization and to identify them according to typologies and technologies of building systems.

Moreover, this first phase made it possible to acquire information on the development of typological and distributive schemes of the flats that, during the 90-year life of the Institute, could be classified in the following phases:

First phase: 1906-1915. The Rule that put into effect the Luzzatti Act of 1904, specifically defined the standards that for half a century identified the typology of "economic popular" housing, fixing minimum standards of cubature, lighting, ventilation, maximum number of floors and building standards for floors, roofs and sanitary. The distributive characteristics of internal spaces are defined by this Rule at the minimum level as possible, because it focuses especially on the economical aspect. The main aspects considered were the following: the entry to the flat was made directly from the stairwell in the kitchen and from here to the others rooms; the rooms were quite large since many people could live in the same one; the kitchen was also very big because all the day-time activities took place there. It was also the only heated room, with a big fireplace and a "secchiaio" (bucket spot) useful for many uses. There were not, or were quite small, any corridors, access rooms or halls, in order to increase the useful area of rooms in equal condition of covered areas (i.e. of costs). Where there were corridors, the medium habitable area per flat was about 14.00 square meters, with the sanitary located outside the flat, sometimes serving more than one flat. The medium useful area of habitable rooms (kitchen included) was about 17.00 square meters, and the utilities' area (sanitary, fireplace, "secchiaio") was of about 5.00 square meters.

Second phase: 1919-1934. In this second phase the flat, previously considered only according to an economical aspect, becomes more rational and comfortable, and makes it possible to guarantee better living conditions. There is a tendency to make the rooms and the kitchen more independent, by introducing halls; the sanitary, even if smaller, is located inside the flat; the medium useful area of habitable rooms is about 17.50 square meters, the utilities' area (sanitary, fireplace, "secchiaio") is about 6.50 square meters, the halls and access rooms are about 6.70

square meters.

Third phase: 1934-1940. The main typologies in this phase consist of the so called "popolari" and "popolarissime" flats and represent a moment of withdrawal in the typological evolution of flats, due to the comeback of the concept of affordability. The only new change consists in the fact that both typologies introduce, for the first time a "small kitchen" in alcove for the mere function of cooking food. This is separated from the living room by a partition wall where the rooms appear because the hall does not make them independent. The differences between the two types depend essentially on dimensions: a) *Popolarissime*: the useful area tends to the minimum, in fact it has been reduced, thanks to special legislative measures, below the limits of the minimum standard considered by the 1908 Act, that prescribes that popular flats have to respect local building rules, and the Sanitarian Act of 1907. The useful medium area of rooms is about 12.00 square meters, the utilities' area (sanitary and small kitchen) is about 3.25 square meters, and the hall is about 1.90 square meters; b) *Popolari*: the useful medium area of rooms is about 16.45 square meters, the utilities' area (sanitary and small kitchen) is about 6.80 square meters, the hall is about 3.70 square meters. Another defining element of these typologies is the fact that they combined, for the first time, the sanitary and small kitchen with a single technological cavaedium for discharges, chimney, etc

Fourth phase: 1945-1985. In these forty years, the building typologies, even if different because of the Acts succeeding in time, have homogeneous characteristics. In fact, in most cases, each flat has a hall; the kitchen, from a big one in the first phase to a small one in alcove, is better dimensioned according to the specific use, and the living room acquires more importance; the bedrooms are separated from the living rooms; the useful medium area is about 14.00 square meters, utilities (bathroom and kitchen) are about 13.00 square meters, hall and access rooms are about 7.00 square meters.

Fifth phase: after 1985. From 1985 on, the improvement of habitable and technological quality of flats is combined with the general concept that all flats have to be provided with spaces that, as for number and typologies, can respond to the necessities of the families they are destined to. The new idea is that all flats have to be divided in order to assure a sufficient level of autonomy to adults or older people, living with a family couple. Also, generally speaking, new attention is given to "special users" to whom flats are destined. For this reason, medium and big flats have to provide, in average, 4 beds, and an independent space with a dedicated sanitary. The resulting schemes are a modern interpretation of the first schemes of 1906.

According to architectonical typology, there are the following types of buildings:

Isolated: low residential typologies that lodge few families and are located in a town planning scheme, with low building density. The building, whose internal parts are accessible by a single stairwell, is isolated on both sides;

Terrace: linked single residential building typologies, usually low, repeated identically and articulated in order to maintain building continuity. Moreover, this organization makes it possible, with adequate orientation, to attain an homogeneous sun exposure;

Tower building: an isolated building with vertical development maintaining a moderate occupation of soil;

Apartment house: the building is developed according to the favourite direction. Among the variable elements that characterize this typology there are the number and the placement of vertical ways in relation to the number of flats served or existing on each floor;

Duplex: this architectonical typology presents a flat located on two levels;

Gallery houses: a building that presents an overhanging structure from the external wall, edged by a baluster or railing, consisting of an accessible area that turns around the building or a part of it, both on the inside and outside.

The analysis of the building methods used for the structural system makes it possible to find out the following building technologies: **masonry**; **evolved-traditional**: mixed procedure using reinforced concrete, bricks and structures with flat elements (bearing walls and/or large panels and lofts); **traditional in reinforced concrete with linear elements' structures** (pillars and beams); **processes based on industrialized techniques** (tunnel); **processes based on the use of prefabricated elements.**

Figure 153 shows the relations between building technologies and building typologies, according to the period of the building.

The E.P.E.R. intervention consisted of building, performing maintenance and rehabilitation in 88 of the 101 municipalities of the Province of Potenza. In the municipalities of Castelnuovo Lucano, Fardella and Teana interventions are under way for 14 flats each.

On the whole, the E.P.E.R. realized 917 buildings for a total of 7.268 flats and 1.698 premises. Even if in the municipality of Potenza a tendency to construct buildings of "apartment" typology is confirmed (581 buildings corresponding to 63,36% of the whole built in the Province), there are also other recurrent architectonical typologies. In fact, in all municipalities the "terrace" typology is widely represented, with a complex of 116 buildings (12,65%) and duplex buildings (127 buildings corresponding to 13,85% of the whole) in 27 of the 88 Municipalities, among which it's worth mentioning the quantitative consistency of interventions in the specific architectonical type, such as the Municipality of Avigliano, Bella, Filiano, Oppido, Palazzo and Muro Lucano. There is quite a sufficient number of isolated buildings (84 corresponding to 9,16%); there are tower type ones (6 buildings corresponding to 0,65% of the whole) in Rionero and Melfi; in the municipality of Picerno (1 building) and Venosa (2 buildings) are also the only examples of "gallery" type buildings.

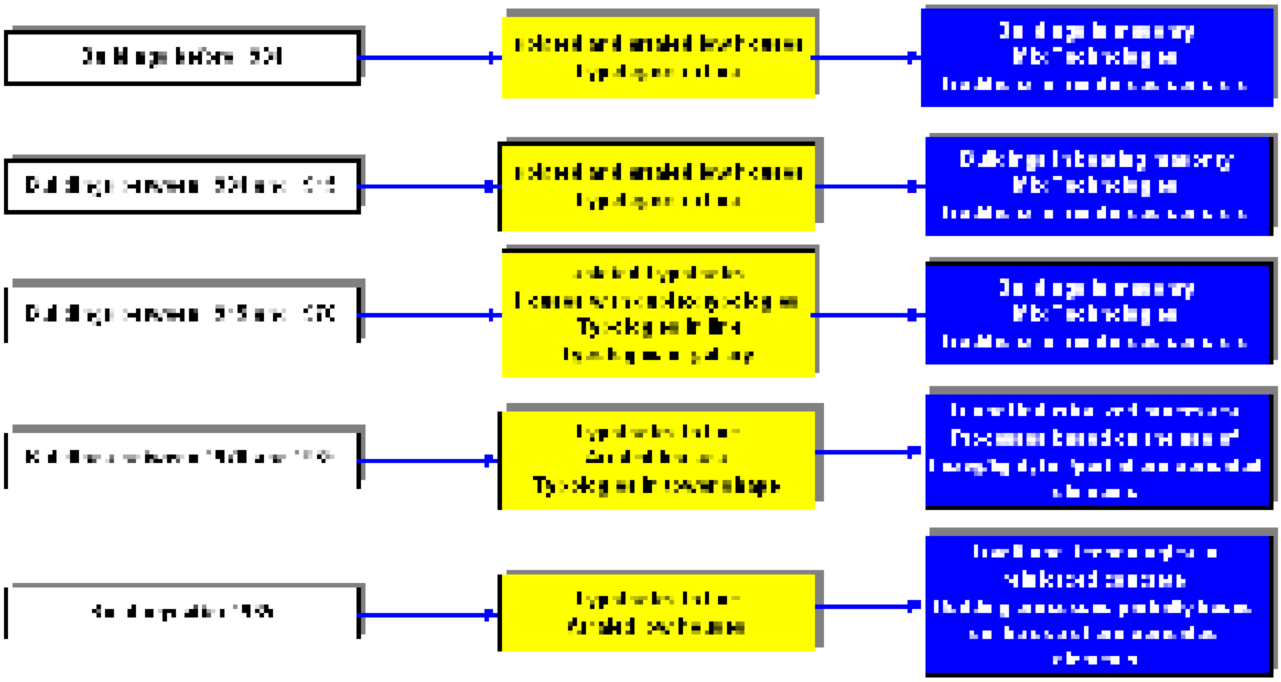

Figure 153 – Relations between building pathologies and building typologies

As for building techniques, 98,69% of interventions are made with reinforced concrete (53,87%) and mixed system (44,82%); the only example of "tunnel" industrialized process is in the municipality of Rapolla, and there are 11 buildings, corresponding to 1,20% of the whole, constructed entirely with prefabricated systems, in the municipalities of Chiaromonte, Francavilla, Picerno, Rapolla, Rionero, Lagonegro, Lauria. The results of the analysis of the data about the 917 buildings are particularly worth of notice: none of them has been built before the second after-war period and almost 40% have been built between the 1970's and nowadays.

As for the aggregate data analysis regarding the E.P.E.R. flat real estate, we can observe that the public real estate, according to a national trend, is concentrated in the main town, with an incidence of more than 25%. The whole intervention is noticeable: 1.224 buildings, 12.562 flats (among which 6.365 are rented), 2.321 premises (among which 979 are rented), 1 sports ground (in Lagonegro), 2 social centres whose concession was given to the Caritas (in Melfi and Lagonegro).

68,87% of the buildings are "apartment", while the "terrace" type, "duplex" and "isolated" buildings are about 10%; in Venosa and Picerno there are unique three "gallery" buildings; in Potenza, Rionero and Melfi there are 19 "tower" buildings. With the only exceptions mentioned above of tunnel industrialized building processes (in Potenza and Rapolla), almost 58,24% of the prefabricated buildings constructed in some municipalities of the Province of Potenza (11 prefabricated buildings corresponding to 0,90% of the whole) and 15 masonry buildings in Potenza, are made in reinforced concrete, while the other 39,30% are made with a mixed system.

Almost all of the intervention was realized between the 1945 and 1985; not much more than 2% was built between the first and the second after-war period. Finally, 7,68% of buildings were built after 1985 and 33,33% after 1970, which partially explains their generally good maintenance levels.

4.7.3 RELATIONSHIPS BETWEEN TECHNOLOGICAL SOLUTIONS AND RECURRING PATHOLOGIES – FREQUENT PROJECTUAL AND BUILDING MISTAKES

The analysis about the typical pathologies of the E.P.E.R. flat real estate of Potenza, allowed us to determine the main building pathologies and collect information about "critical points" of the buildings.

We linked the identification of single pathologies and their causes to two sources: - the *traditional* techniques, to the French Unified Technical Documents (D.T.U.) about the main categories of buildings; the *non-traditional* techniques, to the Avis Téchniques, realized by C.S.T.B. special commissions.

Through this analysis we could organize a data bank, the starting point for the realization of a computerized database comprising all data about the observed defects.

After a disaggregate analysis of pathologies, splitting up each building into sub-systems, and classifying the pathologies found in each part of the building, the defects were grouped mainly in: *a.* leaking of water from coverings; *b.* leaking of water from walls; *c.* separation of the floors; *d.* separation of lining; *e.* lack of waterproofing; *f.* thermic dispersions (thermal bridges); *g.* acoustic dispersions (acoustic bridges); *h.* moulds and stains; *i.* diffuse pathologies caused by condensation; *l.* pathologies caused by installations and discharges; *m.* pathologies caused by window and door frames; *n.* cracks.

These classes of defects were aggregated according:

1. the subjective importance: leaking of water from coverings (15,61%) and walls (10,29%), moulds and stains (14,02%) unrepaired thermal bridges (12,15%), lack of waterproofing (10,94%), floor detachment (8,54%) and lining separation (6,95%), cracks (6,38%), and finally defects of window and door frames (4,80%) installations (especially heating plant and waterworks) and discharges (5,25%);

2. the cost of rehabilitation interventions: the more expensive ones derived from problems caused by leaking of water from coverings (35,29%), floors separation (17,65%), moulds (17,64%), lining separation (11,76%), leaking of water from walls (10,39%), installations and discharges (8,83%), cracks (2,95%);

3. the relationship between different building techniques, as showed in figure 154.

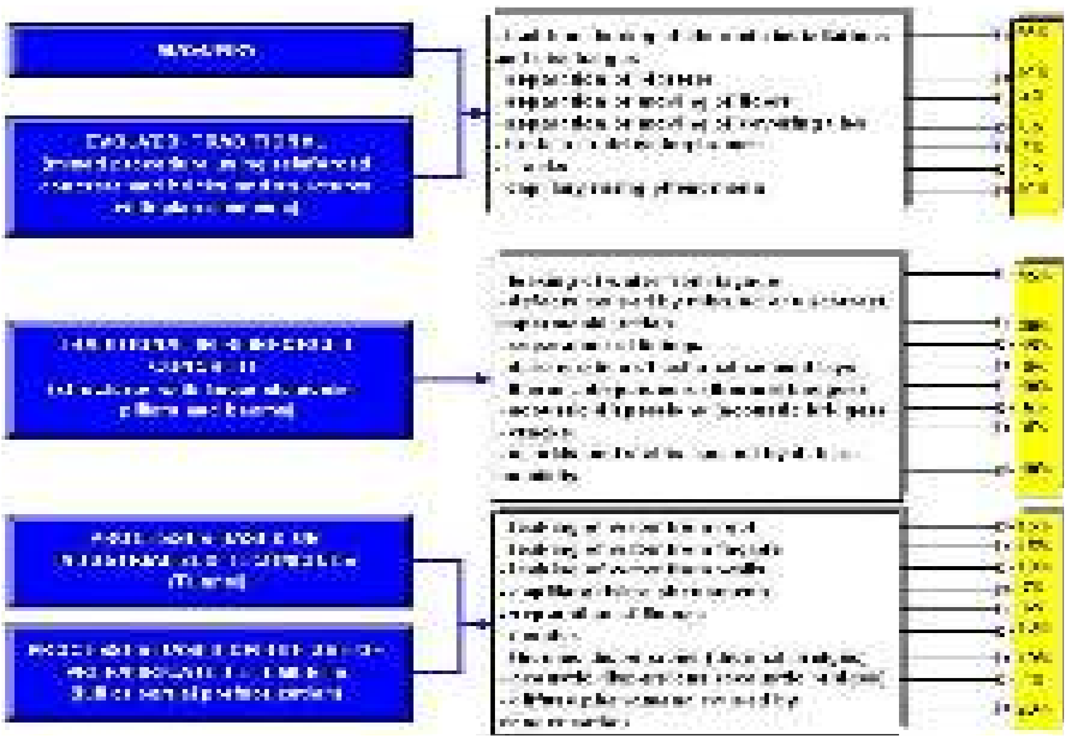

Figure 154 – Relations between building typology and pathologies

Putting aside a series of pathologies strictly due to more or less serious project mistakes (such as those shown in figure 155) and, more frequently, due to mistakes in the realization of different parts of the works (despite the frequent attempts to take particular precautions and devices to avoid condensation), the pathologies due to condensation are particularly serious.

The hygrothermal quality rules concern three main aspects: thermal insulation, superficial condensation risks, and condensation risks in external walls. Generally speaking, the condensation concerns the rooms whose walls have a superficial temperature lower than the dew's point.

DESIGN MISTAKES	
Coverings	**External Vertical closings**
- wrong evaluation in technical leans to define the way the water flows down; - wrong distribution of downspouts, who must be in areas easy to inspect; wrong evaluation of the possibility of self-cleaning of the floor; - inadequate design of the layers and their superposition, in relation to the vapour passage, to the static and thermal forces, to the ageing phenomena; - wrong evaluation of thermic expansion joints in relation to seasonal and daily thermic variations, with consequent damaging of sheath; - wrong planning of the perimeter flashings in correspondence of parapets, skylights, entries, chimneys, that show heights and geometries not adequate to protect from water and any other weather' s factor, causing humidity, internal stains, etc.; - wrong planning or realization of the impermeable connection between the parapet and the floor, causing damages by leaking of water, evaporation and condensation, etc.; - wrong planning of parapets, showing an inopportune geometry and, consequently, inadequate resistance to the dynamic of winds and rain water, which often causes cracks, leaking of water, stains and spots of façade, etc.	**- reduced thickness of reinforced concrete sheets of the external layer of vertical panel, which caused a premature corrosion of reinforce-ments; - wrong selection of materials or stopping up components related to climatic and environmental characteristics of the site (seasonal temperature, significant thermic variations, wind direction and force, geo-morphological condition, polluting sources, etc.) which causes different kind of phenomena such as stains of the walls, condensation, moulds, etc. In other words, it is necessary to chose a complex of materials for the building system considering the effective environmental aggressiveness and the use of the structure; - wrong or missing design of thermal bridges, making them hunchbacked, causing cracks and damages, etc. - wrong geometry of perimeter of external frames that aids the water to stagnate on the sides of the frame, which causes the oxidation of the window frame and stains, by lateral drippings of water and plaster detachment; - wrong geometries of formal design of the façade, finishing not adequately harmonized or not adequately connected to the support, making visible critical points caused by leaking or water stagnation, material separation, internal moulds, etc; - wrong prediction about the performance of the external layer as for hygrometric, climatic, polluting characteristics of the site, causing stains and spots, materials separation, etc.**

Figure 155 – Main mistakes in project of horizontal covering closings and external vertical closings

4.7.4 CONCLUSIONS

The analysis confirms that this kind of pathologies can be linked once again to mistakes in design and execution (see figure 156), but also to mistakes in conducting the heating system and the "wrong use" of the building.

Among the more frequent design mistakes there are:

— unrepaired thermal bridges;

— mistakes in the appraisal of useful conductivity of used materials, insulating or not, that can be even higher in comparison to theoretical ones resulting from laboratory tests;

— slightly insulating elements that can't avoid condensation and do not respect what the Act

10/91 prescribes;
- non-use of devices to control relative humidity that, in use, can be considerably high because of the internal water vapour released into the air by people, equipment (cooking stoves, gas stoves, etc.) and by specific actions (cooking foods, washing up and drying dishes, clothes and floors, vapour from baths, showers, etc.).

Among the most frequent execution mistakes there are:

- incorrect placement of insulating materials (for example without vapour barrier or, even worst, with a vapour barrier on the insulating "cold face");
- insulating materials thicker than the ones calculated by the designer;
- insulation decay in time;
- using of external plaster that prevents the inside water vapour from exiting to the outside.

As for mistakes in heating system's installation and overall bad functioning of the building, the following can be mentioned:

- intermittent use of the heating system, accompanied by long idle periods. The intermittence in heating causes condensation especially in bedrooms, where during the night there is a high production of water vapour because of the breathing during sleep. This leads to an air temperature drop and, consequently, of the walls' temperature;
- separation of heating by autonomous systems. In fact, the problem of different timing of autonomous systems causes a less efficient heating of the whole building and this can be an issue in the facing rooms.

Finally, as for the wrong use of the building, we noticed:

- the abolition, due to aesthetical reasons, of the cooker-hood in the kitchen;

Figure 156 – An example of the lack of attention in the assembling and junction of components in a building made with load bearing great prefabricated panels. Some of them present breaches and most joints are not adequately sealed. It is inevitable that there is leakage of water and infiltration of air inside the habitable rooms, in addition to thermal bridges. It is also an example of the wrong design of water piping and collecting system, which leads to leakage of water caused by stagnation, cracks, lack of cohesion of concrete and to stains on external surfaces.

- the presence of furniture and pictures at external walls. This is the case, for example, of built-in wardrobes set against the facing perimetrical alls of the bedrooms. The furniture, which usually has a noticeable thermal resistance, causes a drop in the temperature of the walls they are set against, as well as in the temperature of the corresponding thermal bridges, which causes condensation and mould stains.

Schematically, the main causes of humidity in the flats are:

- percolations of rain water from roofs, cracks in the walls, open joints, holes in materials, etc.: this kind of problems is quite unusual (with the exception of damaged waterproofing), and can be easily identified; plus, all the experts know the recovering techniques;
- leakage of water from foundations: the above explanation also applies, even if the recovering techniques are more complex and expensive;
- water leaks in canalizations, water-pipes, drains, etc.: usually the rehabilitation is made a long time before the mould forms;
- excessive hygroscopicity of lining;
- humidity in building;
- superficial condensation.

The standardization of recurrent defects made it possible on the one hand to achieve "*databanks of failure cases*", and on the other, to express typical solutions for rehabilitation works, that have the value of "*rules-conforming solutions*", the "*rules of art*".

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CHAPTER 5

CASE STUDIES

5.1 COMPARATIVE DIAGNOSTIC AS AN INSTRUMENT FOR INTERVENTION'S DURABILITY

(Antonella Guida and Antonello Pagliuca)

5.1.1 INTRODUCTION

Interventions for conservation of built heritage, either historic or not, is appropriate only if there is a deep knowledge of the building.

In fact, it is not possible to ignore the importance of the diagnostic phase both "to control" the interventions and to study the global features of the system, especially in long-term maintenance programs, in order to guarantee the interventions' durability.

The research focuses on the possibility/need to operate a comprehensive diagnosis of the building and to make a comparison between the different tests performed; it is possible to cross the results obtained from tests - destructive or not – in order to get data that is qualitatively and quantitatively correct and extensible to the whole building. The analysis and qualification of the buildings' walls point out that this approach is useful for the classification of building pathological events and for the implementation of innovative solutions, in order to guarantee the durability of interventions.

5.1.2 THE "SUITABLE" INTERVENTION CHOICE

Nowadays, monumental heritage's safeguard and conservation shows various aspects, which help us to identify the so-called "architectonic emergencies". This is linked to the great number and urgency of the cases to solve and, at the same time, to the short availability of time and economic resources.

When observing a deteriorated monument, the restoration planner should answer essentially three questions: "if", "where" and "how" to carry out a restoration. It is possible to add a fourth question, where the economic aspect is strongly present: "when" to carry out a restoration. In order to suitably answer these questions, it is necessary to follow specifications, find out the deterioration's cause, assess the residual safety, restoration's necessity and suitability and, finally, choose the suitable intervention and define its procedures. In particular, the definition of intervention goes from the choice of the intervention techniques to their implementation. The comparisons between two variables: the possible technical choices and the deterioration's degree are what characterize the type of intervention.

In order to increase the safety factor of a structure, it is possible to operate in two ways: removing the causes or opposing the effects. The first type of intervention involves a reduction of the loads which burden the structure.

The second type, which tends to oppose the effects more than removing the causes, involves integrations or additions to the materials or structures, keeping geometries and loads unchanged. When the type of intervention is defined, it is suitable to carry it out using a unit-methodology, which involves interventions not differentiated in time. It is also fundamental that the technicians in charge of the structural restoration, make their decisions not only according to the materials' durability, but also to the changed parts' rigidity, in comparison with the adjacent ones. Putting too rigid materials into the monument means drawing most loads on these areas. As a consequence, there is the possibility of fragile and localized breakings, which can, in turn, trigger a mechanism of chaining collapse. .For this reason, it is often advisable to replace deteriorated elements with materials which are similar to the original ones or which have similar straining behaviours.

Thus,, when analysing the outline of the problem of monument's structural restorations, it is clear how both ethics and knowledge must coexist in the technician in charge of the intervention. In fact, prof. J. Kerisel [Kerisel 1981], a famous researcher, has recently stated that if artists were necessary to construct old buildings, nowadays artists are still needed to assure their safeguard. This inevitably emphasizes the problem of training and experience of workers involved in structural restorations. This promotional effort, supported by indispensable financing, legal and administrative means, could paradoxically build in the near future a "therapeutical intervention", which could be more successful for our monumental heritage [A.Guida et al 2005].

5.1.3 THE CASE STUDY: MATHERA'S CATHEDRAL

This research focus upon the Matera's Cathedral, a massive architectural structure, built at the end of the XIII century. In Apulian Romanesque style, it keeps its formal and architectonic connotations almost unchanged on the outside, even though some interventions have substantially changed the style on the inside. It does not show any evident deterioration signs of its static structure, but pathologies are visible on the outside.

A big dark spot (figure 157) affects the whole building along its perimeter. It seems to be caused by a deep phreatic rise, which could have resulted in rising damp pathologies on the whole building, even though the spot's height is makes it doubtful, since it rarely reaches such heights. This kind of humidity rises from the subsoil and may be fed either by dispersed water or by an underground water table [Croce S. 1994]. The first one is usually the result of local - and limited - causes, such as insufficient collecting of rain-waters, leakage from wells or water pipes; all these causes may produce local imbibition of the soil touching the foundations. They often affect just one side of the building, and can be solved through suitable means.. On the contrary, underground water tables are neither removable, nor controlled. They affect the building uniformly from the basis; showing maximum rise height on North/North-East façades and minimum rise height on the sunniest areas; it is widely spread to every building in the area and does not show any changes in the re-ascending height.

Figure 157 – The big dark spot on the external wall of the Cathedral

In a superficial analysis of the outer walls of Matera's Cathedral [Esposti W. et al 1983],the presence of rising damp could be observed as the result of an underground water table, since there are neither wells nor hollows which could allow the underground backwater. However, some hydrogeological surveys carried out in this area, have shown that there has never been any underground water tables, either now or in the past. After excluding this possibility, a thermographic analysis (figure 158) of the whole building was conducted, in order to understand the dark spot's nature.

Figure 158 – The thermographic survey of the Cathedral's façade

The thermographic survey [Eads L.G. et al 2000] is a non-destructive test, which is based on the physical principle of energy transmission by radiance, through electromagnetic radiation. The wavelength of the radiation emitted by an object depends on its temperature, according to Wien' s law $\Phi = A/T$. The wavelengths emitted by objects usually belong to the band spectrum, which is situated into the infrared area (Φ included between 0.78 mm and 0.3 mm). Only at about 6000 K (sun's surface's temperature), the emission is at the center of the visible spectrum. If you move an object's surface from a higher temperature point to a lower temperature point, the quantity of radiant energy emitted in the two different areas will change (due to Stefan's law) and the wavelength of the emitted radiation will also change [Rosina E., 1997].

Thermo vision scanners explore the analysed surface using different wavelengths and point out the change in radiant energy strength, according to standards UNI 10824. As this radiant energy is linked to the object's temperature only through emissivity, it is possible to evaluate the object's temperature by knowing its emissivity coefficient and, likewise, it is possible to evaluate its emissivity knowing the object's temperature [Volpini S. et al 1990]. A suitable optical scanner system analyses the whole area of the camera, shooting details, and then generates an electric sign in a sequence, according to the picture's thermal information and proportional to its strength, which is reproduced on the kinescope. Every change in surface temperature will correspond to a similar change in the radiant strength. The kinescope gives a particular color to these changes.

The analysis was carried out in March 9th 2007. The outer temperature was 8°C and the air's relative humidity was at 53%. An unusual result was attained by the analysis of the achieved thermographic pictures: the lighter areas, corresponding to the dark spot on the façade, are actually hotter rather than colder, as it would have been expected if there had been rising damp [Massa S., 1987]. This result showed that the masonry was actually dry, and the fact that it was hotter in the whole building's lower areas - even though at different heights - was probably justified by a different behaviour of the stone when absorbing solar radiation, which probably led to variations in the material's emission capacity. The big dark spot would seem to absorb more sunlight than the rest of the building, which has a lighter color, typical of the local stone, called "tufa". The physical mechanism that is responsible for this process is the irradiation that transfers the heat in the form of electromagnetic waves, in this specific case, directly from masonry irradiated by sunlight. For this reason, the spot is hotter than the rest of the building. However, further tests on physical-chemical properties of the material, and more detailed petrographic analysis are today being implemented to determine the exact nature of the phenomenon.

This kind of survey provides results, which are qualitatively acceptable, but it does not provide any quantitative information. .This research aims to examine the possibility of comparing these qualitative results (deriving from the photograms' analysis), with the quantitative results, which derive from destructive tests such as the determination of the humid section's diagram.

In order to carry out this test, three cores have been taken out of the southern wall of the Cathedral, corresponding to S. Eustachio's altar.

Drilling reached 80 cm inside the wall and got to the outer hewn stone. The 6 cm diameter cores have been carried out using a HIUTI DD-250E coring machine dry. They were taken out of walls along the same lines, 50 cm apart from the other, starting at a height of 2,70 m from the floor. The samples were wrapped up in plastic film, covered with paraffin and then catalogued for further analysis.

The analysis has led to the definition of the water content in the samples. In fact, the material was weighed upon extraction, and after being dried in an oven. The difference between the two weighings defined the value of the water content in the tested samples. It is necessary that every weighing operation is carried out using the same scales in order to reduce instrumental mistakes. After weighing, every container and sample were put in a 110°C oven for at least 16 hours and no more than 24 hours, according to the ASTM D 2216-80, D 2974-87 and CNR-UNI 10008 directions. When dried, the samples were weighed again: subtracting this value to the one obtained before the drying process, and comparing it to the dry weight, provided the value of the water content in every sample (table 16). So, by analysing the data, it is clear that the masonry is dry and the water content of the samples is the material's physiological content.

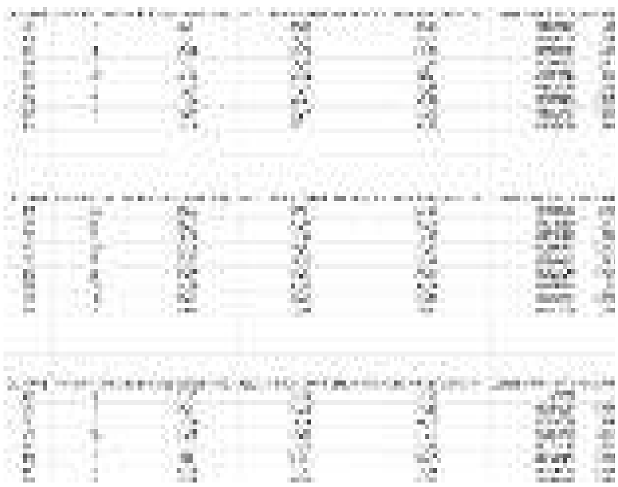
5.1.4 CONCLUSION

This research shows how it is possible to compare the results achieved from different kinds of tests. To do so, it is necessary to correlate the results, in order to provide systematized information on the conservation state of every monument, reducing the damage and endangerment of each structure.

The study aims to accomplish an applicative methodology more respectful of the built heritage, in order to avoid simple acritical transpositions of the calculation models in recovery interventions.

The proposed methodology is based on a fundamental aspect of the refurbishment and/or restoration project, which is the cognitive aspect, through tests on site and in laboratory. The following step is the realization - and then the validation - of the intervention and a periodical monitoring.

Table 16 – The value of the water's content in every sample



Technological tests were conduted to determine the physical, chemical and mechanical characteristics of the materials used in the construction of the buildings in

Sassi (tufa, mortar, plaster), and to evaluate the compatibility (chemical, physical, mechanical) with eventual new materials used in restoration interventions and even to validate the choices made during some interventions.

This accurately projected survey plan presents itself as a further knowledge instrument and a mean to program a recovery intervention, respecting the ancient heritage and without compromising the requisites of durability and safety.

This research can also contributes to increment the typology of the tests to carry out on masonry; in fact, in relation to all the problems of tests and investigations, it is necessary to have more than one kind of survey, in order to build an organic plan to compare the results, contributing to a more complete cognitive frame. Often, only by comparing the analysis of more data, resulting from different surveys, is it possible to interpret the real phenomena and ensure the necessary parameters to realize a correct intervention.

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further investigation for acquiring knowledge and data about the performance in time of this building systems is a necessity.

5.2 CAUSES: PROCESSES WHERE THERE IS LACK OF QUALITY CONTROL, ERRORS IN PLANNING OR EXECUTING

(Filiberto Lembo)

5.2.1 INTRODUCTION

In Italy, the spread of industrialization techniques in building (spatial cells in reinforced concrete, great load-bearing panels systems, tunnels and banches-tables with cladding panels, steel structures and mixed steel-in situ concrete) has been limited to high-densely populated urban areas, where important interventions of residential building were made thanks to public aid, particularly to resolve emergencies, such as the 1980 earthquake in Campania and Basilicata, or the 1983 bradyseism of Pozzuoli (near Naples).

Thanks to a thorough analysis of 14 interventions, involving an amount of about 4.500 flats, it was noticed a lack of structural quality control processes both on the project and execution, typical of the administrative instruments used for these works: the Italian systems of awarding contracts "*concessione di sola costruzione*", "*appalto concorso*", "*appalto integrato*", in which project, construction and quantity-quality control are all supervised by the contractor, which is responsible only of building, but not for assuring maintenance, management or durability of the real estate. This seems to be one of the main causes of quick decay and reduced durability that characterizes most of these interventions, corroborating the negative experience of other European Countries, such as England [Lembo, 1988].

From a specifically technical point of view, all interventions were studied considering aging conditions, quality performance, functional defects or anomalies, decay situations and more frequent pathologies, trying to find out causes and possible solutions through the analysis of single cases and the diagnosis of the decay process.

New failure cases were discovered, which are worthy of the attention of specialists, in order to avoid their recurrence. It was also noticed that a correct project and execution allow for durable and efficient performance on these building systems and both prejudices and unconditioned enthusiasm are not justified. In other words,

5.2.2 SURVEY FIELD

The research group coordinated by Prof. Arch. Filiberto Lembo is currently working in the Faculty of Engineering at the University of Basilicata – Potenza, and previously operated in the Faculty of Architecture of Rome – *La Sapienza*; in the last twenty five years it has been working on collecting data about pathologies and durability characteristics of the industrialized building systems of residential structures, by means of surveys, which are often repeated in a cyclical manner after a few years, on the most relevant interventions of the middle-south of Italy (Lazio, Campania and Basilicata).

As a matter of fact, the following quarters were analyzed:

- Roma, *Corviale Nord e Sud*, Piano di Zona n. 61 - n. 1.080 flats of subsidized buildings - large bearing panels system model FINTECH-ITALCAMUS – years 1972-74 (planning), years 1976-1985 (carrying out);
- Roma, *Giardinetti*, Piano di Zona n. 27 - n. 252 flats of agreed buildings - large bearing panels system model COSEDIN S.p.A. (Balency MBM) – years 1975-76;
- Roma, *Casal dé Pazzi*, Piano di Zona n 10-11- n. 152 flats of agreed buildings - large bearing panels system model CEVIP S.p.A. - years 1984-85;
- Pozzuoli (Napoli), *Monterusciello* - subsidized buildings after natural disaster (bradyseism of Pozzuoli 1983) - Lot n. 6 - n. 216 flats - prefabricated reinforced concrete pillars, floors made by prédalle, cladding with large concrete panel; staircases cast in-situ running as wind-brace - cladding with large prefabricated panels - years 1984-85;
- Pozzuoli (Napoli), *Monterusciello* - Lot n. 8 - n. 148 flats - large bearing panels system model FORAP - years 1984-85;
- Pozzuoli (Napoli), *Monterusciello* - Lot n. 8 - n. 148 flats - large bearing panels system model FORAP - years 1984-85;
- Pozzuoli (Napoli), *Monterusciello* - Lot n. 9 - n. 156 flats - large bearing panels system - years 1984-85;
- Pozzuoli (Napoli), *Monterusciello* - Lot n. 11 - n. 154 flats - steel "pillar-beam" system, floors made by "prédalles", staircases cast in-situ with slipform, running as wind-brace - cladding in large prefabricated panels - years 1984-85;

- Pozzuoli (Napoli), *Monterusciello* -Lot n. 13 - n. 150 flats - reinforced concrete spatial cells made by ZANUSSI Edilizia Industrializzata S.p.A. – years 1984-85;
- Pomigliano d'Arco (Napoli) – *Comparto n. 7* – Settori residenziali n.1, 2, 3 and 4 – n. (128+127+147+60) = n. 462 flats of subsidized buildings after the 1980 earthquake – large bearing panels system model PEIKERT, years 1981 (planning) - 1986 (end of works);
- Atripalda (Avellino), *Alvanite District* - n. 303 flats of subsidized buildings after the 1980 earthquake – tunnel forms and cladding in large prefabricated panels - years 1982-91;
- Avellino, *some districts* - n. 1.023 flats of subsidized buildings after the 1980 earthquake - steel system, floors made by "prédalles" and staircase cast in-situ, running as wind-brace (or, in same districts) tunnels and precast cladding panels – years 1981-86 until 1991;
- Potenza, Cocuzzo "*Serpentone" District* – n. 138 flats of subsidized buildings - tunnels and precast cladding panels - years 1976-80;
- Potenza, Cocuzzo "Serpentone" District – n. 138 flats of subsidized buildings - reinforced concrete beam-pillar system cast in-situ and REP beams (mixed steel–reinforced concrete) years 1975-84;
- Melfi (Potenza), n. 125 flats of subsidized buildings - reinforced concrete spatial cells made by ZANUSSI Edilizia Industrializzata S.p.A.;

This is a homogeneous and representative sample of the so-called "industrialized construction" building technologies, which, apart from these special applications, have never been used in Italy so far, especially in the south and center of the Country.

5.2.3 RELATION BETWEEN PROCESS QUALITY AND PRODUCT QUALITY

The surveys were mainly focused on buildings constructed after special procedures, which have been currently replaced by the *integrated contract* (i.e. "*appalto integrato*"). For this reason, we believe that still now there is the risk of lack of control, which is typical of the examples considered above.

When these procedures are applied (they are generally justified by the specific technical complexity of the building techniques to be used, with respect to short lengths of time for realization), the building contractor proposes the executive design and qualitative features to be respected, as well as the specifications and general conditions. So, the judge and the defendant are the same person; the control system, based on the hypothesis that both the project and the specifications are to be defined prior to the constructor's choice, is, as a matter of fact, completely bypassed. In particular, in some of these procedures, the Contractor, apart from arranging the design, nominates and pays the clerk of works, eliminating any sort of objection.. The extreme consequence of this process is that, in some cases, buildings, at the time of their completion, are already "not habitable", with plenty of severe pathologies (as occurred in Pomigliano d'Arco (Napoli), at *Comparto n° 7*).

This is the consequence of a particular trend, also seen in past years in other European countries, in which low cost dwellings are constructed by means of different kinds of inducements – as it happened in Great Britain - through industrialized building systems guaranteed by the newly created Government structures, in order to step over the classical validation processes [Lembo 1988].

So, while in Italy the Societies of Validation need designers to pay closer attention to less important items of a traditional project, the most important contracts enjoy special conditions which produce a decisive reduction in building quality and/or durability; very often *the technological innovation is the Trojan horse for bypassing control systems*.

It is necessary to remember that the ILO - International Labour Organization – stated that it is not useful to study in detail a working process that has not been rationalized (i.e. it means nothing to apply a *time study* on a process which has not been defined trough a *study of the methods*. They say: "*you can't use the spoon if you must yet use the grader*". In Pathology Studies it happens the same: what you see is condensation, or water entering trough the envelope. There is a technical problem, but it's *the spoon*; the veritable, primary cause (*the grader*) it's the lack of quality control in all or in part of the process. So it's impossible to avoid faults in design or execution stages.

5.2.3.1 ROMA, CORVIALE

This is the case of an eleven-floor building which width is divided in three parts, the overall length being approximately one kilometer; it contains 1080 dwellings of subsidized construction, a "street" on the seventh floor, with (prevised, but never realized) offices and shops, meeting halls, and at the ground floor and first floor, garages, storerooms and so on (see figure 159).

The very first mistake was made at the time of conception: the scale of intervention was typical of a technical solution with large bearing panels on basement cast in situ, but the design planning did not consider longitudinal cross bracing walls, because the structural designer (Riccardo Morandi, famous for his experience on bridges) considered a *purpose made solution,* based on cast in situ transverse walls made with slip forms and precast floors, to please the architectural designers (coordinated by Prof. Arch. Mauro Fiorentino) who wanted a variable section for each floor, with an intermediate floor ("street"), free from longitudinal walls.

Figure 159 - Roma, Corviale North and South, n.1.080 flats of subsidized buildings realized with large bearing panels system

It was a *competitive contract*, which allowed the company to consider alternative technical solutions for the development of the original project: in the end, the building was realized as it should have, with large bearing panels on a cast in situ ground floor, made with industrialized formworks. Nevertheless, it was necessary to ensure wind bracing trough *elastic cross bracing keys*, due to the absence of longitudinal walls and the unlined openings of the various floors.

It was necessary to employ an enormous quantity of steel bars for pillars in the panels (four to six in each), with a very small cover, because of the reduced thickness (16 cm) of the panels. As a matter of fact, the damaging effects of carbonation were not considered at all, thanks to the structural Standards, which allow the designer to consider very small dimensions for the cover (see figure 160).

Besides this, there are other incredible inattentions: cladding is made with one layer of reinforced concrete panels, insulated from inside, joined "head to head", whose impermeability is assured only by the sealant, and the only possible periodical maintenance requires a 35 meters impalement on a inclined plane (the garage covering). The panels on the façade - 6,00 meters length, 1,50 meters high and about 10 centimeters thick - are sustained by two omega shaped black steel rods welded to a plate on the floor, in the screed for installations, and two welded black steel plates corresponding to the transversal walls, covered with a 15 millimeters thick cement mortar: they are prone to movement. These same panels have a border on the inside - under the window sill - to hold the window frame, which produces a remarkable thermal bridge and causes condensations to drip on the inner lining, made of the most hydrophilic material possible, such as gypsum plaster lath bricks or expanded clay. The same problem about thermal bridges is also true for internal loggias, galleries and cavaediums (see figure 160).

Figure 160 - Roma, Corviale North and South, characteristics of the industrialized building system

It seems that the building knowledge was forgotten on the verge of the industrialized building techniques and that neither literature or rules – even if produced by mutual consent and by foreigners Bureaus - have been able to predict the performance in time of building solutions [Lembo 1978].

5.2.3.2 POZZUOLI, MONTERUSCIELLO

It was a program to realize n. 4.000 flats with all facilities, after the bradyseism of the 1983, to build a new city, organized by the Faculty of Architecture of the University of Naples. The total cost was of 104 Mld in Italian lires (about 52.162.000, 00 euro). The announcement of competition was signed by the Minister of Civil Protection, On. Vincenzo Scotti on the 7 November 1983.

The announcement of competition was signed by the Minister of Civil Protection, On. Vincenzo Scotti on the 7 November 1983.

The announcement of competition declares that:

"4) Structures of high – Claddings – Partitions" - "The Building Company that participates in this competition will use the proper compatible system of prefabrication related to the horizontal and vertical structures and to the external claddings and interior partitions. No plasterboard."- "5) Coverings" - "The roofs and the flat roofs will be waterproofed with sheathe bitumen on top of an adequate insulation. The floors are boarded with squared tiling of cement. The discharge of the meteoric water it will be trough roses gully grating and tubs made of heavy pvc. The flat roof will be paved with small squares of cement

leaned on support of pvc."- "6) Thermic and acoustic insulations" - "The insulation will be according to the law 30 April 1976, n.373. The partitions between different flats will be isolated acoustically with rock wool or equivalent materials."

It is quite clear that the constructive knowledge has been "thrown out the door" because the Minister based his decisions on a generalized document and delivered all concessions of the project, the realization and the management of the 150-flat building to the Consortium of Building Companies, which carried out buildings free from any restrictions or control.

In most part of the construction with large prefabricated panels (see figure 161), they used one layer of multitubolar panels, interiorly isolated with a light insulating panel and inner lining in plaster. That produces pathologies of condensation near the thermic dispersions, and vertical widespread cracks at the joint of the panels, due to the thermal shock of Summer-Winter cycles to which the structures are subjected.

Figure 161 - Pozzuoli (Napoli), Monterusciello n. 148 flats of subsidized buildings realized with large bearing panels

Some Building Companies modified the project, placing insulations (covered of thin plastic plaster) on the outside, in which case the pathologies are completely absent. Although the bearing "*solid sandwich*" panels were used widespread, they later fell in disuse in most European, due to their very poor thermal qualities. Here it shows that besides the large presence of "head to head" joints between the prefabricated panels – about 50% of the total, built with very low waterproofing and durability, scarce attention was paid to the positioning of the panels.

Also, it has been verified a very widespread problem of insufficient covering of the reinforcement of the bearing and cladding panels, of the prefabricated floor and staircase (cast in situ). Little squares of the joints or sections of black steel, used in parts of the connections, quickly corroded because of differential aeration. The lack of the cut of capillarity on the ground floor caused enormous flows of capillarity. All that can cause inhabitability of the rooms.

Most of the time the roofs are wrong. The most diffused type is the "*hot roof*", but without vapor barrier under the insulation and with the sheath on the top of the waterproofing. All that produces condensation and moulds on the inside of the lofts. The bad conception and construction of the waterworks causes frequent leaks, which in pre-fabricated structures are very important. That way; the "liberality" towards those who carried out the work, has had heavy effects on the quality and durability of buildings, preventing them from being kept in a good state of preservation.

This bad performance is indubitably due to the type of license used, in which the Contractor is also the designer and clerk of works, and to the lack of specifications, which are descriptive and proposed by the holder at the same time of the economical offer. But it is hard to believe that this could not have also been due also to the fact that the project and the construction processes were not evaluated by independent and competent entities.

5.2.4 CONCLUSIONS

The same reflection about the Constructive Program of Pozzuoli – *Monterusciello* can be applied to the one related to the 20.000 apartments, built in the area of Naples and its hinterland, to fulfill the requirements of the people, following the earthquake of 1980. This included the interventions of Pomigliano d'Arco, and the one foreseen for the boroughs affected by the same earthquake in Campania and in Basilicata, to which belongs Avellino, which are the greatest interventions.

Here too, the institute of the "*concessione di sola costruzione*" ("*to build without succeeding maintenance & management*") was responsible by many faults, attributing the supersion of the planning, carrying out and work to the holders, and bringing about strong inefficiencies. Except for a few exceptions, the interventions suffer of the same pathologies and problems of durability, as if entire generations of engineers have failed their task.

But such conclusion could be unfair and at the same time lead astray. It could be very important for engineers to have a deeper university preparation or PhD on the characteristics and pathologies of industrialized buildings: sometimes, after reading the documents, inspection reports, ratification and approval opinions, it seems designers didn't master the object, even when operating with high standards. Certainly, it could be difficult to expect that cavaedium between the floors of 25 x 25 cm, made of a U-shaped 7cm-thick reinforced concrete panel, housing the pipes of the heating plant and waterworks, could be the origin of the air-drift, responsible for the condensation inside (Roma, *Giardinetti*).

Furthermore, it could be difficult to expect that in a steel structure made of pillars and beams, treated only with anti-rust and synthetic paint, with lofts of reinforced concrete made of prédalle, the most corroded parts after 18 years are not the ground HEB profiles of the pilotis subject to the rain, but the beams on the intrados of the porches or loggias, subjected to *differential aeration*, because they are only partially incorporated in the lofts. These factors, inherent to the project and product, can turn out to be like "*spoons*", in the presence of factors of different weight and importance, which work like the "*grader*" to level the ground.

These are the ones linked to the process, and particularly to the terms of contract, when they are done with public money. The history of the industrialization of building in Italy, delaminated through the study of the constructions, will show that it has not been used to gainhigher levels of productivity or performance, nor shorter times for the realization of buildings, as they announced for many years. It has been used to justify the concentration of contracts and, then, the choice of highly qualified holders from local Building Companies. To assure that, the contracts must be profitable and desirable, not only valuable and concentrated, but run in a very peaceful way and with the right of choice. Now we understand why so many project, conception, execution and verification mistakes are all concentrated in these constructions.

Also, it is important to call out among the causes of mistakes and pathologies, those that are not completely technical, when it is proven that their importance could be fundamental.

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5.3 MIXED STRUCTURE BUILDINGS OF THE EARLY XX CENTURY: PATHOLGIES AND CAUSES

(Giambattista De Tommasi, Fabio Fatiguso, Mariella De Fino and Albina Scioti)

5.3.1 INTRODUCTION

Materials naturally undergo physical and performance decay, which becomes pathological, whenever the development is abrupt and rapid and the extent is substantial, due to inner defects and outer disturbing factors, rather than inherent ageing. Design and construction defects, as well as missing and poor maintenance, might be responsible for speeding up the physiological decay and, thus, requiring repair and refurbishment measures.

As far as the mixed structure buildings of the early XX century are concerned, a preliminary analysis points out that construction systems were characterized by several techniques and solutions, which were developed in a very short time. In fact, at that time, an overall transformation occurred following the Industrial Revolution. As a consequence, in the building sector, traditional materials and components were progressively combined and/or replaced with modern ones. Owing to the increase of scientific studies and industrial patents about products and processes, the new technological solutions showed increasing complexity and variety. Moreover, they were developed, regardless the traditional analysis of the whole building. As a result, the connections among different sub-systems were neglected, leading to potential critical points.

The analysis of more than 110 housing buildings in Puglia and Basilicata Regions (South Italy), dating back to 1900-1940, was carried out. First, it comprised the research on technical handbooks of that period [Breymann, G.A., 1885; Koniger O., 1902; Levi, C., 1907; Donghi, 1906]; the historical, technical and typological classification of buildings and; the identification of construction materials and structural technologies (at building and component scale). Then, it focused on all the mixed structure typologies (including some sub-typologies), in terms of definition of possible critical points for decay development and possible pathological alterations, connected with obsolescence processes [De Tommasi G. and Fatiguso F., 2008].

Specifically, physical obsolescence was mainly analysed from the observation of decay and deterioration in materials and components, as well as pathology patterns. Such obsolescence seemed the result of a very peculiar occurrence, namely the combination of traditional and innovative materials, generally showing poor compatibility and the unawareness of actual performances of new systems by the early XX century designers and builders.

It was observed that physiological and pathological ageing simultaneously occur and affect each other, causing reduced service life and functionality of building components and sub-systems. As a result, they are not always easy to differentiate. The present contribution is going to discuss the results of the above-mentioned analysis, with specific reference to slabs and staircases.

5.3.2 SLABS

The investigation of case studies, the technical research on historical handbooks, and the performance assessment have enabled the definition of most common pathology patterns and relative possible causes. Table 17 shows a summary of the results for different typologies of slabs.

In general, iron primary structure slabs show critical interaction with the secondary structure, leading to swelling, detachment and cracking of intrados plaster at the interface between beams and blocks, particularly for type B2 with natural and artificial blocks (small vaults, small slabs, brick blocks) and type B4, with concrete components (figure 162). Those pathology patterns might be due to poor physical and mechanical compatibility between different materials; lacking protection of iron intrados surface; missing blocks, specifically shaped for connecting and covering the beams; iron corrosion for aggressive environmental conditions and/or inadequate maintenance.

Figure 162 - Type B2 iron slab. Plaster swelling and detachment

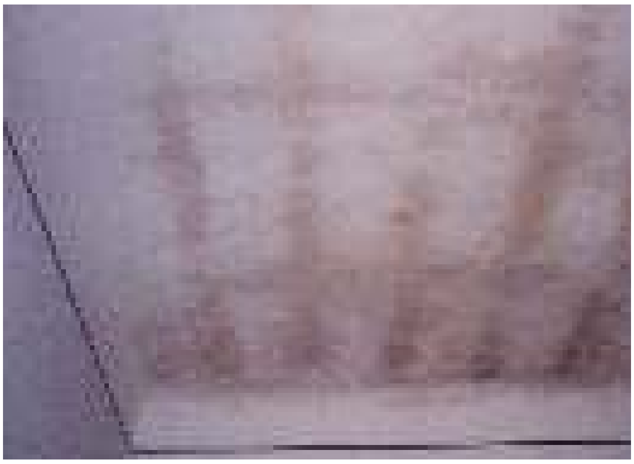

Figure 163 - Type C2 concrete slab. Intrados surface decay and stains

Deformation of iron beams, with subsequent cracking and detachment of extrados floor tiles, is very common, as well. In type B2a, it also causes the brick small vaults close to the walls to fall down. In this case, problems are connected with deficient iron beam bearing section, compared with loads and span; poor mechanical, chemical and physical compatibility between different materials (especially mechanical compatibility between slab and floor tiles); missing blocks, specifically shaped for connecting the slab with the walls.

Specific pathologies of iron beams are also detectable. Corroded beams show intrados surface decay and stains. In type B3, iron plates are similarly corroded. Aggressive environmental conditions and/or inadequate maintenance of floor tiles might be responsible for that. In addition, in type B3 and B4, surface condensation might occur, due to lacking protection of iron intrados surface and and/or inadequate maintenance. Moreover, type B4, with concrete components, might show intrados surface cracking, caused by poor mechanical, chemical and physical compatibility between different materials; high deformability of iron beams; construction defects; ineffective hardening of concrete; overloads.

As far as type C slabs (concrete beams and plain concrete slab/ brick blocs) are concerned, it should be observed that intrados surface decay and stains, as well as swelling, detachment and cracking of intrados plaster (figure 163) are quite common. Possible causes are poor mechanical, chemical and physical compatibility between different materials and inadequate maintenance. Further pathology patterns concern the decay of concrete under the reinforcement bars (lack, mouldering...); cracking and detachment of concrete elements (figure 164). They might be due to construction defects; ineffective hardening of concrete; overloads; deficient iron beam bearing section; iron corrosion. For type C2, those factors might also cause the brick blocks to fall down (figure 165).

Figure 164 - Type C1 concrete slab. Decay of concrete under the reinforcement bars

Figure 165 - Type C1 concrete slab. Brick blocks falling down

5.3.3 STAIRCASES

The above-described analysis was also carried out for different typologies of staircases, as summarised in Table 18. First, it should be mentioned that some pathology patterns occur in all the cases. In detail, intrados and side surfaces of steps and landings extensively show decay and stains, with minor differences among the typologies. The causes are lacking protection of elements, poor chemical, mechanical and physical compatibility among different materials, aggressive environmental conditions and inappropriate use, especially in terms of maintenance of extrados surfaces (figure 166).

It is also common to observe the loss of adhesion and subsequent detachment of plaster close to the steps. Such a pathology pattern is generally quite severe, again due to poor chemical and physical compatibility among different materials, inappropriate use and wrong/missing maintenance interventions (figure 167). Stone covering the steps is damaged, as well, by colour alterations, disaggregation, decohesion, and sometimes detachment (figure 168). Possible causes are inappropriate use, poor chemical and physical compatibility among different materials, and different dilation rate of elements. Similarly, for all the typologies, rails show corrosion and deformation, regardless their material. Wrong/missing maintenance, aggressive environmental conditions and inappropriate use (including vandalism) are responsible for that.

Figure 166 - Type B1c staircase. Side surface decay and corrosion of iron beams

Figure 167 - Type B1c staircase. Intrados plaster detachment

With specific reference to iron primary structure staircases, they show critical interaction with the secondary structure, leading to swelling and cracking of intrados plaster at the interface between beams and blocks, particularly for types B1a/B1b/B1c, with intrados slab or vault rampant made out of natural and artificial blocks and type B2, with intrados slab or vault rampant made out of concrete. Such pathologies are mainly connected with poor mechanical and physical compatibility among different materials, as well as missing protection and possible corrosion of iron beams at the intrados. In fact, it is quite common the detection of surface alterations of the beams, with subsequent bearing section reduction, whenever aggressive environmental conditions and wrong/missing maintenance happened.

In most cases, although less common than the previously described pathology patterns, deformations of iron beams can be observed that might trigger cracking and detachment of tiles on steps and landings. In typologies B1c, such deformations can also make the brick blocks of the vault rampant to fall down. Possible causes are deficient iron beam bearing section, compared with loads and span; poor mechanical, chemical and physical compatibility between different materials - especially mechanical compatibility with tiles on steps and landings (figure 169). As far as type B1d is concerned, disaggregation, decohesion and detachment of cantilever stone steps is quite frequent, because poor dimensional and mechanical compatibility, as well as differential dilation, might be present between contiguous blocks and between blocks and iron rail. Inappropriate use might worsen such a phenomenon [De Fino et alii, 2010]

Figure 168 - Type C1 staircase. Disaggregation, decohesion and detachment of stone covering

Figure 169 - Type B1a staircase. Cracking and detachment of tiles on landings

Particularly for type B2, the iron beams with concrete components undergo condensation, because intrados surfaces were not well protected and maintenance works were never carried out. Intrados surfaces are also cracked and detached, due to poor mechanical, chemical and physical compatibility between different materials; high deformability of iron beams; construction defects; ineffective hardening of concrete; overloads.

Finally, for type C, the concrete beams with concrete or brick blocks undergo the above mentioned cracking and detachment of extrados tiles and intrados plaster, as well as decay of concrete under the reinforcement bars (lack, mouldering,...) and cracking/detachment of concrete elements. They might be due to construction defects; ineffective hardening of concrete; overloads; deficient iron beam bearing section; iron corrosion. For type C1, those factors might also cause the brick blocks to fall down.

5.3.4 CONCLUSIONS

The analysis confirmed that mixed structure buildings of the early XX century, realized with a wide variety of materials and techniques, have undergone rapid and severe physical/technological deterioration over the last decades. Their state of conservation, affecting the service life and functionality of all the components, is the result of combined physiological and pathological factors. Particularly, some critical conditions can be observed, when modern materials were used, regardless the compatibility with traditional systems and the assessment of actual performances, especially in terms of reliability and durability. Moreover, in most cases, the development of formal and typological solutions was carried out, without considering any possible maintenance problem. Consequently, the study has pointed out that mixed structure buildings require repair, refurbishment and/or maintenance works, wherever a failure has occurred. Nevertheless, they need a comprehensive performance retrofitting, with specific attention toward the connections between traditional and modern materials. Finally, the analysis of pathology processes can address the proposal of suitable interventions, which should comprise surface protection, improvement of interfaces between old and new elements, reconstruction of decayed components, static reinforcement and conformity to legislation in force.

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Table 17 - Matrix of pathologies and causes for mixed structure slabs

MATRIX OF PATHOLOGIES															
SLABS					**PATHOLOGY PATTERNS**	**POSSIBLE CAUSES**						**INVESTIGATION TOOLS**			
CATEGORIES		**TYPES**		**SUBTYPES**											
B	**IRON**	**1**	**WOOD**		**AS4**	**C4**	**C7**					**V1**	**V3**	**V7**	
					AS5	**C4**	**C6**	**C7**				**V1**	**V3**	**V15**	
					AS8	**C5**	**C9**	**C10**				**V1**	**V6**	**V8**	
					AS9	**C3**	**C5**	**C6**	**C7**			**V1**	**V2**		
		2	**NATURAL OR ARTIFICIAL BLOCKS**	**SMALL VAULTS**	**AS1**	**C1**	**C2**	**C4**	**C7**			**V1**	**V2**		
					AS2	**C1**	**C2**	**C5**	**C6**	**C7**		**V1**			
					AS3	**C1**	**C2**	**C4**	**C7**			**V1**	**V2**		
				SMALL SLABS	**AS4**	**C1**	**C4**	**C6**	**C7**			**V1**	**V7**		
					AS5	**C1**	**C4**	**C6**	**C7**			**V1**	**V3**	**V15**	
					AS6	**C1**	**C4**	**C6**	**C7**			**V1**	**V3**	**V15**	
				BRICK BLOCKS	**AS7**	**C2**	**C5**					**V1**			
					AS8	**C5**	**C9**	**C10**				**V1**	**V6**	**V8**	**V16**
					AS9	**C3**	**C5**	**C6**	**C7**			**V1**	**V2**		
		3	**IRON PLATES**		**AS6**	**C1**	**C4**	**C6**	**C7**			**V1**	**V3**	**V15**	
					AS8	**C5**	**C9**	**C10**				**V1**	**V6**	**V8**	**V16**
					AS9	**C3**	**C5**	**C6**	**C7**			**V1**	**V2**		
					AS10	**C4**	**C6**	**C11**				**V1**	**V10**		
					AS11	**C4**	**C6**	**C11**	**C12**			**V1**	**V15**		
		4	**CONCRETE COMPONENTS**		**AS2**	**C1**	**C2**	**C5**	**C6**	**C7**		**V1**			
					AS3	**C1**	**C2**	**C4**	**C7**			**V1**	**V2**		
					AS4	**C1**	**C4**	**C6**	**C7**			**V1**	**V7**		
					AS8	**C5**	**C9**	**C10**				**V1**	**V6**	**V8**	**V16**
					AS9	**C3**	**C5**	**C6**	**C7**			**V1**	**V2**		
					AS12	**C4**	**C5**	**C6**	**C8**	**C9**	**C10**	**V1**			
C	**CONCRETE**	**1**	**ARTIFICIAL BLOCKS**		**AS3**	**C4**	**C7**	**C8**				**V1**	**V2**		
					AS4	**C4**	**C6**	**C7**	**C8**	**C11**		**V1**	**V7**		
					AS9	**C3**	**C6**	**C7**	**C10**			**V1**	**V2**		
					AS13	**C4**	**C6**	**C8**	**C9**	**C10**	**C11**	**V1**	**V2**	**V10**	
					AS14	**C4**	**C6**	**C8**	**C11**			**V1**	**V2**	**V10**	
					AS15	**C4**	**C6**	**C8**	**C11**			**V1**	**V2**	**V10**	
					AS16	**C4**	**C6**	**C8**	**C11**	**C13**		**V1**	**V5**	**V10**	
					AS17	**C4**	**C6**	**C7**	**C8**	**C11**		**V1**	**V5**	**V12**	
					AS18	**C8**	**C9**	**C10**				**V1**	**V8**	**V16**	
		2	**PLAIN CONCRETE SLAB**		**AS3**	**C4**	**C7**	**C8**				**V1**	**V2**		
					AS4	**C4**	**C6**	**C7**	**C8**	**C11**		**V1**	**V7**		
					AS9	**C3**	**C6**	**C7**	**C10**			**V1**	**V2**		
					AS13	**C4**	**C6**	**C8**	**C9**	**C10**	**C11**	**V1**	**V2**	**V10**	
					AS15	**C4**	**C6**	**C8**	**C11**			**V1**	**V2**	**V10**	
					AS16	**C4**	**C6**	**C8**	**C11**	**C13**		**V1**	**V5**	**V10**	
					AS17	**C4**	**C6**	**C7**	**C8**	**C11**		**V1**	**V5**	**V12**	
					AS18	**C8**	**C9**	**C10**				**V1**	**V8**	**V16**	
					AS19	**C4**	**C6**	**C9**	**C10**			**V1**	**V2**		
					AS20	**C4**	**C7**	**C8**	**C11**			**V1**			

MATRIX OF PATHOLOGIES			
PATHOLOGY PATTERNS			
AS1	Swelling of intrados plaster at the interface between iron beams and blocks	*AS11*	Corrosion of metallic plates
AS2	Cracking of intrados plaster at the interface between iron beams and blocks	*AS12*	Cracking of concrete slab intrados surface
AS3	Detachment of intrados plaster	*AS13*	Cracking
AS4	Surface decay and stains	*AS14*	Mouldering
AS5	Corrosion of iron beams	*AS15*	Detachment
AS6	Corrosion of iron beams with reduction of bearing section	*AS16*	Lacking concrete under reinforcement bars
AS7	Brick blocks close to walls falling down	*AS17*	Corrosion of reinforcement bars
AS8	Deformation of iron beams	*AS18*	Deformations
AS9	Cracking and detachment of extrados floor tiles	*AS19*	Brick blocks falling down
AS10	Surface condensation	*AS20*	Cracking of intrados plaster
POSSIBLE CAUSES			
C1	Missing protection of intrados surface of iron beams	*C8*	Ineffective hardening of concrete
C2	Missing blocks, specifically shaped for connecting and covering the beams	*C9*	Overloads
C3	Poor mechanical compatibility between slab and floor tiles	*C10*	Deficient bearing sections
C4	Poor physical and chemical compatibility between different materials	*C11*	Aggressive environmental conditions
C5	High deformability oh iron beams	*C12*	Lacking protection of intrados surface of metallic plates
C6	Lacking maintenance	*C13*	Corrosion of reinforcement bars
C7	Inadequate maintenance of floor tiles		
INVESTIGATION TOOLS			
V1	Direct visual inspection	*V9*	Ultrasonic testing
V2	Surface beating by hand or small rubber hammer	*V10*	Thermography
V3	Inspection of connections with walls	*V11*	Endoscopy
V4	Removal of concrete under reinforcement bars	*V12*	Magnometry
V5	Chemical analysis of samples	*V13*	Sclerometry
V6	Geometry survey	*V14*	Bore hole drilling/Sampling
V7	Photography/ Photogrammetry survey	*V15*	Measuring of corrosion potential
V8	Analytic assessment	*V16*	Comparison with legislation in force

Table 18 - Matrix of pathologies and causes for mixed structure staircases

MATRIX OF PATHOLOGIES															
STAIRCASES					PATHOLOGY PATTERNS	POSSIBLE CAUSES						INVESTIGATION TOOLS			
CATEGORIES		TYPES		SUBTYPES											
B	IRON	1	NATURAL OR ARTIFICIAL ELEMENTS	A – SLAB RAMPANT LONGITUDINAL BEAM	ACV1	C1	C3	C4	C7			V1	V2		
					ACV2	C1	C3	C5	C6	C7		V1			
					ACV3	C1	C3	C4	C7			V1	V2		
				B- SLAB RAMPANT TRANSVERSAL BEAMS	ACV4	C1	C4	C6	C7			V1	V7		
					ACV5	C1	C4	C6	C7			V1	V3	V15	
					ACV6	C1	C4	C6	C7			V1	V3	V15	
				C – VAULT RAMPANT	ACV7	C3	C5					V1			
					ACV8	C5	C9	C10				V1	V6	V8	V16
					ACV9	C2	C5	C6	C7			V1	V2		
				D –CANTILIVER STEP	ACV20	C1	C3	C13	C14			V1	V2		
					ACV21 - ACV22	C4	C13	C14				V1	V2		
					ACV23 - ACV24	C1	C6	C11	C14			V1	V2		
		2	CEMENT BASED MATERIALS	A – SLAB RAMPANT	ACV2	C1	C3	C5	C6	C7		V1			
					ACV3	C1	C3	C4	C7			V1	V2		
					ACV4	C1	C4	C6	C7			V1	V7		
					ACV8	C5	C9	C10				V1	V6	V8	V16
					ACV9	C2	C5	C6	C7			V1	V2		
				B – VAULT RAMPANT	ACV10	C4	C6	C11				V1			
					ACV12 - ACV13	C4	C6	C8	C9	C10	C11	V1	V2	V10	
					ACV19	C4	C7	C8	C11			V1			
					ACV21 - ACV22	C4	C13	C14				V1	V2		
					ACV23 - ACV24	C1	C6	C11	C14			V1	V2		
C	CONCRETE	1	ARTIFICIAL ELEMENTS		ACV3	C1	C3	C4	C7			V1	V2		
					ACV4	C1	C4	C6	C7			V1	V7		
					ACV9	C2	C5	C6	C7			V1	V2		
					ACV12 - ACV13	C4	C6	C8	C9	C10	C11	V1	V2	V10	
					ACV15	C4	C6	C8	C11	C13		V1	V5	V10	
					ACV16	C4	C6	C7	C8	C11		V1	V5	V12	
					ACV17	C8	C9	C10				V1	V8	V16	
					ACV18	C4	C6	C9	C10			V1	V2		
					ACV21 - ACV22	C4	C13	C14				V1	V2		
					ACV23 - ACV24	C1	C6	C11	C14			V1	V2		
		2	CONCRETE		ACV3	C1	C3	C4	C7			V1	V2		
					ACV4	C1	C4	C6	C7			V1	V7		
					ACV9	C2	C5	C6	C7			V1	V2		
					ACV12 - ACV13	C4	C6	C8	C9	C10	C11	V1	V2	V10	
					ACV15	C4	C6	C8	C11	C12		V1	V5	V10	
					ACV16	C4	C6	C7	C8	C11		V1	V5	V12	
					ACV17	C8	C9	C10				V1	V8	V16	
					ACV19	C4	C7	C8	C11			V1			
					ACV21 - ACV22	C4	C13	C14				V1	V2		
					ACV23 - ACV24	C1	C6	C11	C14			V1	V2		

MATRIX OF PATHOLOGIES			
PATHOLOGY PATTERNS			
ACV1	Swelling of intrados plaster at the interface between iron beams and blocks	*ACV13*	Detachment
ACV2	Cracking of intrados plaster at the interface between iron beams and blocks	*ACV14*	Mouldering
ACV3	Loss of adhesion and detachment of plaster	*ACV15*	Lacking concrete under reinforcement bars
ACV4	Surface decay and stains	*ACV16*	Corrosion of reinforcement bars
ACV5	Corrosion of iron beams	*ACV17*	Deformations
ACV6	Corrosion of iron beams with reduction of bearing section	*ACV18*	Brick blocks falling down
ACV7	Brick blocks close to walls falling down	*ACV19*	Cracking of intrados plaster
ACV8	Deformation of iron beams	*ACV20*	Disaggregation, decohesion and detachment of stone blocks
ACV9	Cracking and detachment of extrados floor tiles	*ACV21*	Disaggregation, decohesion and detachment of stone covering
ACV10	Surface condensation	*ACV22*	Colour alteration of stone covering
ACV11	Cracking of concrete slab intrados surface	*ACV23*	Deformation of rail elements
ACV12	Cracking	*ACV24*	Corrosion of rail elements
POSSIBLE CAUSES			
C1	Lacking protection of element/layer	*C8*	Ineffective hardening of concrete
C2	Poor mechanical compatibility with floor tiles	*C9*	Overloads
C3	Poor mechanical compatibility among different materials	*C10*	Deficient bearing sections
C4	Poor chemical and physical compatibility among different materials	*C11*	Aggressive environmental conditions
C5	High deformability oh iron beams	*C12*	Corrosion of reinforcement bars
C6	Lacking maintenance	*C13*	Differential dilations
C7	Inadequate maintenance of floor tiles	*C14*	Inappropriate use
INVESTIGATION TOOLS			
V1	Direct visual inspection	*V9*	Ultrasonic testing
V2	Surface beating by hand or small rubber hammer	*V10*	Thermography
V3	Inspection of connections with walls	*V11*	Endoscopy
V4	Removal of concrete under reinforcement bars	*V12*	Magnometry
V5	Chemical analysis of samples	*V13*	Sclerometry
V6	Geometry survey	*V14*	Bore hole drilling/Sampling
V7	Photography/ Photogrammetry survey	*V15*	Measuring of corrosion potential
V8	Analytic assessment	*V16*	Comparison with legislation in force

5.4 THE DURABILITY OF BUILT HERITAGE THROUGH TESTS AND EXPERIMENTATIONS ON SITE

(Antonella Guida and Ippolita Mecca)

5.4.1 INTRODUCTION

The heritage of the past is testimony to the ways that civilizations have lived and transformed the natural environment over the centuries. One can plan appropriate interventions to restore and render usable again, the places and spaces of the past, first, through observation and then by learning about historic buildings. In order to restore historic centers efficiently and with cultural consistency, it is necessary to acquire a detailed understanding of the building materials and techniques used, not only for single buildings, but for an entire heritage site of buildings, which are often the so-called "poor buildings". Thus, one must know how to identify the real building problems and define a methodological process before then passing on to interventions. A methodological intervention has been identified and applied to a study case in which the need to resume a dialogue between the various disciplines that embrace this sector of cultural-historic heritage restoration has been demonstrated. In fact, only through an interdisciplinary approach, is it possible to plan and carry out interventions, limiting possible errors in evaluation and decisions. The quality of the built architectonical space has, nowadays, an important role in all the retrieval and reconversion operations of the urbanized areas in very strongly characterized sites. The Basilicata region is one of those where the environing, landscape and cultural works are at a level of a still plain involvement and they seem to belong to a system where the competitive available and acquirable advantages are at a great level.

The existent building heritage's retrieval holds the whole of the interventions aimed at preserving, recovering, rebuilding and using better the heritage itself through a recovery operation it can be added further value to the item of the intervention itself by means of, on the one hand, the former and partly lost conditions retrieval; on the other hand, by means of the details which are otherwise covered by stratifications settled on works, in order to protect the item against destruction, through its own re-utilizing and re-functionalizing. Any retrieval and restoration procedure and technique of the existing heritage cannot prescind from considering the materials and the building technology used to realize the architectonical work where a necessary intervention is required. The retrieval plan gathers structural, architectural, technical and functional aspects indissolubly. The need to integrate the building heritage's architectural and structural retrieval in a global view of architecture is a recent acquisition. It is opposed to the general and rushed extension to the pre-existent (in particular the historical one) of the safety, comfort and accessibility standards. Buildings can be adapted to these standards at the cost of heavy tampering. If in the past the debate on intervention methodologies was based mostly on their efficacy, nowadays, after a ten-year period of applying, experiments and testing, a new subject has been considered: that is to say the physical, chemical and structural compatibility with the existing manufactured article. The integrated use of traditional and modern technologies seems to be the only way to be followed in order to grant an adequate preservation state and a right philological approach to the cultural work, whatever we consider it.

5.4.2 OPERATIVE PLANNING METHODOLOGY

The methodology identified and applied to a study case, is easily dividable into three larger phases capable of encompassing the entire operative course of action, from the idea of execution to the intervention, as well as the management of the intervention work being undertaken.

The *experimental-knowledge* phase can be subdivided into other micro-phases, which ultimately, give life to the "understanding" of manufactured things. The course of action in various ways or through different processes allows the operator to have as much information as possible about "manufactured things". This is possible above all through collaboration between other disciplines.

The *technical-building* phase can become a new field of experimentation and verification of the types of choices made, in fact, once the work enters into the phase of execution one can already have the first results of the effective validity of the intervention, through:

- Realization of the intervention: propostition and verification of plans;
- productive parameters of the building site, planning activities, etc.)

The *management* phase becomes a natural continuation of the executive phase. This, in addition to maintenance and management of the work, involves monitoring and validation of the intervention over time through tests and a maintenance plan. The validation phase looks at the relationship of the intervention to requirements of reliability, durability, compatibility and the possibility for maintenance, which allows for a definition of Quality over time of the intervention carried-out. Quality over time is a component of global Quality, and guarantees the ability to maintain the performance levels required during the planning phase and verified during its realization, throughout the useful life cycle of the product and/or intervention. Thus, the initial quality of the work is maintained in a determined amount of time, without any additional costs. This methodology has been applied to a study case (the Sassi of Matera) following the various phases described. [Guida & Mecca [2007].

5.4.3 CASE STUDY: THE SASSI OF MATERA

The choice of the Sassi of Matera (figure 170) as a study case, where the durability of the restoration interventions can be evaluated, is for multiple reasons.

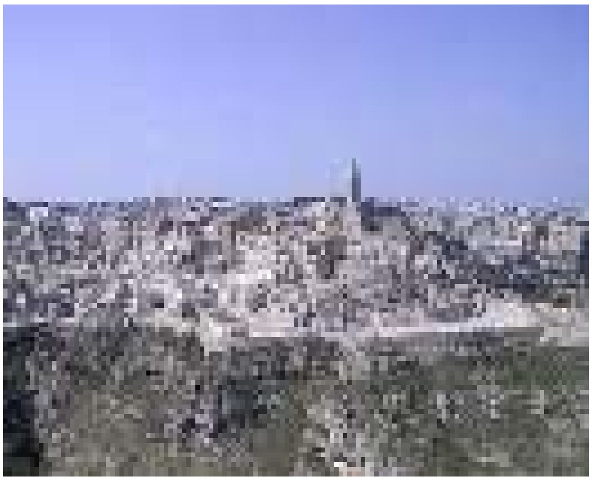

Figure 170 – The Sassi of Matera

The Sassi of Matera constitutes an enormous historic and architectural heritage that in recent years, after more than forty years of abandonment and degradation, is slowly returning to life thanks to restoration interventions. Experiments with new materials on some sites have been made in the course

- Monitoring of operative activities carried out during the intervention (diagnostic analyse

of the work, as well as monitoring of results and evaluating the work in different environments (underground structures which are completely dug-out, mixed structures that are in part dug-out and in part constructed, as well as structures that are completely constructed). The Sassi are characterized by an extremely delicate ecosystem in which there is an ageless equilibrium between the architecture and the environment, in part altered by the work of man, with unique characteristics (geomorphologic adaptations, degradation that has been greatly accentuated by the surrounding environment and by the state of decennary abandonment), which allow one to find solutions, easily transferable and adaptable to the same restoration problems in other, similar contexts. [Guida & Mecca [2007].

5.4.4 RECOVERY INTERVENTIONS DURABILITY IN THE SASSI

Interventions' durability is linked to the new born elements' disposal to become integrated in the pre-existent building both dimensionally and functionally according to a particular service programme, namely according to a suitable compatibility. Considering the Sassi of Matera's values, the intervention suitability is not only the efficiency procedures choice of the required services, but it becomes a precise study about the customer's needs and the possible technological choices in order to satisfy them coherently with pre-existent's architectural features.

For the shape, typology and structure of the Sassi of Matera, the research has concerned the durability assessment in recovery interventions, carried out or going to carry out on the tufa wall with its trimmings. The Sassi architecture typological schemes come from the cave-house, a space set out by two parallel walls and an arched ceiling, a final wall made up of a mass of rocks and the façade made up of tufa blocks. "[…] The house's structure is essential: two side-walls and a cylindrical vault carry out a "built space" while "rocky space" is in the caves, carved as underground passages towards the interior of the Sasso" [Giuffrè & Carocci [1997].

This is the elementary basis [Caniggia & Maffei [1984] of the Sassi architecture, a sub-space inside the following space. In fact even in the most developed houses, palaces and high-class architectures, built in later times with respect to the first housing-settlement in the Sassi, it is possible to find the same shapes and accessories typical of the cave-house. The houses in the Sassi can be considered as serial spaces made up of many elementary cells' union. These sub-spaces are the structural units, which bring about smaller houses due to superimposition, simple approaching or different joining procedures to more complex spaces. This points out "[…] the building structural regularity […]"[Giuffrè & Carocci [1997] in fact studying the house's walls, it can be find out the constant building-features of the walls which are the Sassi block of houses.

"A single, but varied material forms the stone-town." [Giuffrè & Carocci [1997].

For this reason, defining the quality, reliability and durability of the single recovery interventions carried out on the houses' structural load-bearing elements (masonry and mass of rocks) both as for the structures and for hygienic recovery, is equivalent to solve most of the problems linked to the Sassi retrieval. In this case, the durability assessment in recovery interventions is strongly affected by the environment and the existing conditions and therefore by the site itself.

5.4.5 TECHNOLOGICAL TESTS

The need for planning and programming a lab- and on site campaign of new tests and experiments has arisen from the data, on the one hand, coming from previous tests and experiments campaigns carried out in the sample area on traditional and new materials used in recovery interventions. On the other hand, data coming from the even only visual assessment of the first carried out interventions. Some technological tests have been carried out. They were intended to settle the physical, chemical and mechanical features of the materials used in the carrying out of the Sassi houses' (tufa, mortar, plastering) in order to assess the used materials' (physical, chemical and mechanical) compatibility. If necessary, it is possible to use new materials during restorations and also for the choices carried out during the interventions, as in the case of using a specific inorganic reinforcing agent of the rocky mass or typical dehumidifying plastering. The lab-interventions programme has provided:

- It measures the quantity of siliceous and/or silicates aggregate present in the sample;
- Determination of soluble salts sulphates, chlorides and nitrates' content;
- X-ray diffractrometer;
- Thermo-gravimeter analysis (TGA);
- Differential scanning calorimetry (DSC);
- Scanning electron microscope (SEM) analysis. it allows to observe and mark a sample's surface;
- Determination of porosity;
- Absorptance.

This campaign of lab-tests allows engineers to acknowledge the materials' chemical and physical features and it also helps to settle its mechanical characterization, defining its porosity. Furthermore these tests allow to get information about the compatibility between traditional and modern materials, as well as about the surface-deterioration nature. Experiments and new structural tests have been planned both on masonries and mortars.

After obtaining results from the analyses carried-out, lab experiments have been done in order to improve the characteristics of the limestone taken from the underground structures, thanks to the application of reinforcement. In addition to the static degradation both of the rock mass as well as the dwellings (both dug-out and constructed) most of the main problems and degradation found in the underground environments and above ground dwellings in the Sassi are due to the presence of water and lack of ventilation. The hygienic restoration of the underground structures in the Sassi of Matera present notable difficulties due to the extent of the environments to be restored. In fact, in these cases, a need for intervention on the entire wall has been demonstrated, due to the humidity caused by being in constant contact with the rest of the tufa that lines all of the underground walls. In addition, the reinforcement and restoration interventions of these environments are conditioned by the strict regulations that require one to use products that don't cover the walls and that don't alter their color, leaving the environments intact and thus, with all the exterior characteristics of the walls unaltered. [Guida et al. [2003]

It is paramount that the treatment guarantees that the walls have good "perspiration" in order to avoid the formation of superficial layers that could, over time, break-off when under pressure from the water present in the walls to be treated. A product that helps to stop humidity in the walls must be used, slowing down perspiration and eliminating eventual water residue on the walls. This can be achieved through thermo ventilation and forced air exchange. The underground walls act as a sort of "sponge", consequently with a sort of "drainage effect" that once dried, reabsorbs the water present in surrounding areas, which is then in turn given off as humidity into the environment. The solution to the problem clearly lies in intervening in the regulation of both the amount of water as well as the speed at which it is taken from the walls. A lab experiment was carried-out on various samples of limestone taken from some underground environments being studied, which were treated with a stabilizing material. An inorganic material with specific characteristics that are well suited to the needs of the site was used for this experiment: reinforcement that doesn't impede the characteristics of the limestone, that is suited to the chemical structure of the base material (limestone), that allows the limestone to maintain its porousness, that is very durable, not very invasive and which doesn't alter the natural color of the rock. A product such as this is easily prepared on site, but when testing, it is applied in the laboratory to rocks and blocks of stone taken from the structures. The main active ingredient of the product used is a mixture of soluble aluminium. The property of reinforcement is due to the formation of an aluminium gel, which moves into the pores of the stone, creating a type of electrostatic interaction that increases internal cohesion, and reduces crumbling. Experiments brought about the decision to use products with a Lime base (P.C.), an Aluminium base (P.A.) and a Silicon base (P.S.). [Guida & Mecca [2007].

The results obtained have been confirmed both by visual comparison as well as using images from electric scanning microscopes (figure 171 a) and b)) of all samples. The best mixture used for intervention was the P.S. one, in fact, it has:

- The best response in terms of density, porousness and variation;
- The best visual impact, in the almost unaltered coloration of the rocks;
- In the net improvement of the technical characteristics, which are similar for all three products applied.

Figure 171 a)

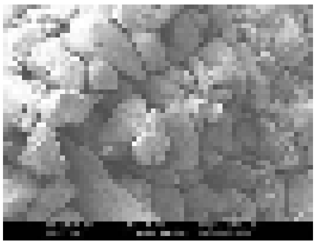

Figure 171 b)

Images from electric scanning microscopes

Aside from the results obtained from the following experiments, the choice to use the P.S. mixture and not the other two for reinforcement, is due to a prediction of greater durability for the intervention, because such a product has the same base composition as the original rock and hypothetically it should have the same degradation. As has just been said, this should be supported by on site experiments and by monitoring over time, in order to really evaluate the duration and processes of degradation.

5.4.6 DAMAGE EVOLUTION OVER TIME IN ANCIENT BUILDING STRUCTURES

In retrieval and conservation field it has been found the necessity of making use of specific techniques to test the structure real conditions of damage, before arranging any intervention. The same procedures can be adopted to test interventions, in particular to check their effectiveness and durability in time.

It is important to know the useful life of a material in order to understand the evolution of the damage in a structure or a building carried out through assembling and joining divisions and components mainly made up of that given material, as it takes place in masonry structures. In some cases the damages on building structures, which often fracture, are due to viscous deformations caused by tensions existing in buildings. These tensions can cause the progressive evolution of the damage with a local rigidity and durability loss, because of their time progression. Furthermore there are other amplifying agents, such as the irregularity of the stresses on walls due to the material's heterogeneity which makes up the masonry, mostly where there is a more faces masonry and the material's fatigue, due to cyclic phenomena, such as variations in temperature, wind and other atmospheric agents.

Experiments and new structural tests have been planned both on masonries and mortars. These two technical elements, because of their own physical and chemical nature, are the cause of rather serious pathologies in the analyzed building context. [Guida & Mecca [2007].

5.4.6.1 STRUCTURAL TESTS

The purpose of this research is applying the same intervention methodology to the sample area, the 'Sassi' of Matera, re-examining what has already been established in a previous study led by a research group from the Polytechnic of Milan. An experimentation campaign and a theoretical modelling will be carried out, holding the features of the material making up the building structures in Matera. The work can be summarized as follows:

— Mechanical characterization of the material;
— Carrying out a theoretical model;

— Applying the model to the simulation of experimental tests;
— Defining the time evolution of the damage;
— Drawing up the guidelines.

The programme of structural tests has provided the carrying out of squashing tests to settle the breaking test load and to assess the differences related to the origin, and creep tests (figure 172 a) and b)) to settle the breaking test load for a material subdued to a steady load.

Figure 172 a)

Figure 172 b)

Creep Tests

A theoretical calculation pattern has arisen from these tests results: for the first time on calcarenite structures, in order to settle the evolution of masonry's damaging, getting the percentage of the first structural damage in comparison with the material's breaking tension.

In order to simulate the real behaviour with the theoretical model, it should be necessary to consider the material's damage, suitably rising the deformation to the i generic.

$$\Delta\varepsilon_i = \Delta\varepsilon_{i\ \mathrm{model}} + \Delta\varepsilon_{i\ \mathrm{damage}}$$

It can be observed how the progress of the two curves – the one drawn from the experimental test and the one drawn from the theoretical model, adding the damage – is very similar.

The first immediate results coming from the numerical treatment can be listed as follows:

- ✓ The first damage of the material subjected to a constant in time load – related to the fracturing tension of the material, which is drawn from a buckling test – is about 40 %.
- ✓ The damage can be correlated to the tension state through a (Δε damage , σ) linear law, ie. (Y = 0.0391X). For this reason, knowing the tension value which a structure is subjected to, the damage value can be drawn;
- ✓ The achieved results could be applied to tufa plates on site.

This theoretical model can be applied to other test pieces and in particular to every masonry structure which has been built using the same examined material.

The pieces of information drawn from the theoretical model can be used in order to restore the efficiency of a masonry subjected to constant and durable loads and therefore an element being easily usable in the sample area, where buildings are made up of calcarenite masonry, but being also extended to other contexts (other historical centres or masonry structures).

The results – which have been drawn from this experimentation - can be used in order to define pre-tensioning to apply to reinforcement scantling devices. For example, in case of building structure showing yielding because of lasting and strong stresses due to the viscous damage, if there are masonry pillars and columns. Procedures can be schematized as follows:

- ✓ Determining the branch gradient of the secondary creep after a campaign of constant load tests;
- ✓ Identifying the damage through theoretical model application;
- ✓ Numerical simulations of constant load tri-axial tests for different confinement values using the above mentioned parameters;
- ✓ Assessing the decrease of the branch gradient of the secondary creep, increasing the confinement tension in order to exclude the third creep starting in a definite time.
- ✓ Dimensioning of the reinforcement scantling to use and defining its pre-tensioning thanks to the tension value added to the numerical model.

This is a more rigorous method to calculate the reinforcement scantling value than the traditional ultimate tensile stress calculation of the reinforced column. [Guida & Mecca [2007].

5.4.6.2 PENETRATION METER TEST

The tests on mortar (Penetration meter test) have been carried out on site (figure 173 and 174) by means of an instrument, planned and produced by the University of the Basilicata Material Tests and Structures Laboratory of the Di.S.G.G (Structures, Geotechniques and Geology applied to Engineering Department). This instrument settles the mechanical features, the angle of friction and the screen curve of the traditional and modern mortars, which have been used as a result of a reinforcement intervention carried out on several monuments in the sample area: and therefore it is possible to check the carried out intervention's efficiency. The aim of the tests is to correlate the numbers of strokes per a penetration millimetre (Stokes per Penetration Unit) with the sanded mortar's quality and some mechanical features such as the "angle of friction", in order to check the only frictional strength of the penetration meter point related to the vertical pressure, ignoring the cohesive component and the "thickness of the joint". Experiments on historical mortars and also on modern mortars of the joints betterment or the dismantling-assembling have been carried out. [Mecca [2006].

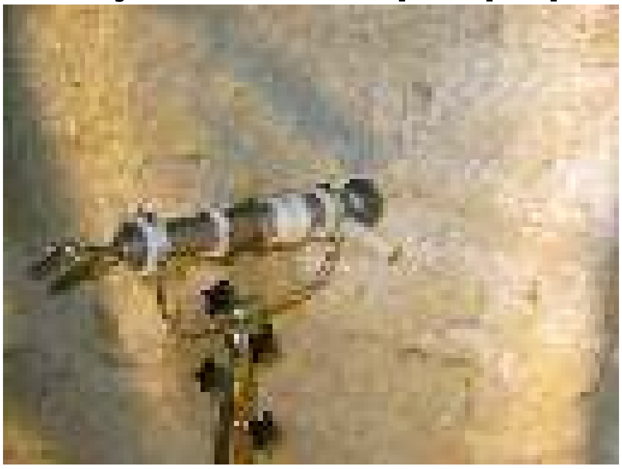

Figure 173 – Penetration meter test

Figure 174 – Penetration meter test

5.4.7 CONCLUSIONS

This precisely planned survey is a further instrument of knowing and programming every recovery intervention, with respect to the ancients, without compromising durability and safety requirements.

This research can help to increase the building test survey; in fact relating to the problems which can take place in a campaign of tests and experiments, a single type of survey will be not enough, but there will be an organic plan where it is possible to compare the different surveys' results. Using this methodology, comparing the data coming from different surveys, It is possible to explain real phenomena and providing the parameters necessary to carry out a correct intervention.

The experimental research of this project constitutes the first phase of understanding the environmental equilibrium, the materials, technology and the problems of the site to be restored. The analyses, still in course, extend to the evaluation of the static and technological interventions, as well as functional adaptations necessary for a correct and complete definition of planning for the durability of the restoration.

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CHAPTER 6

FINAL REMARK

It can be seen that there is a growing concern about the quality of construction, explained by the introduction of specific regulations in the area of comfort but it can also be seen that the buildings constructed in recent years do not have the expected quality. It can even be said that there are thousands of dwellings, built recently, with serious pathologies affecting their use.

The growing complexity of constructions, the lack of knowledge systematization, the absence, in many countries, of an effective system of insurance and guarantees, the speed required for the construction process, the new architectural concerns, the new materials application, the absence in the project team of specialists in building physics and technology are fundamental causes of low quality constructions.

This "state of the art report" on Building Pathology aims to be a contribution to the systematization of information offered by W086 commission with free access to the site to all stakeholders. The Editorial Board, founded by experts in the field of buildings pathology, constitutes the foundation for a quality job standard that we want to perform. We take the opportunity to thank the colleagues that contributed to the compiling of this publication. It was an indispensable work with high quality contributions and importance.

We are aware that that there is still a lot of work to do with the goal of decreasing building pathology or diagnose it correctly. Although, we hope that this "state of the art report" could be a small but an important contribution.

CHAPTER 7

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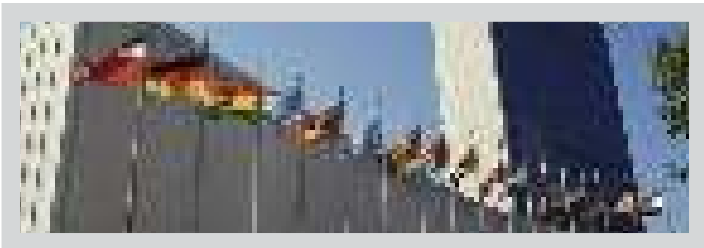

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CIB General Secretariat
Kruisplein 25-G
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The Netherlands
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