Reinforced plaster applications on old buildings rehabilitation

Bruna Alexandra Santos Henriques

Instituto Superior Técnico, University of Lisbon

Lisbon, May 2019

---

1 INTRODUCTION

1.1 GENERAL CONSIDERATIONS

The growing need for rehabilitation is felt throughout the country. One of the major concerns of today's society is the preservation of their built heritage, especially buildings with historical value. The high state of degradation that occurs its most of these buildings leads to an urgent need for their rehabilitation.

With the evolution of construction, in the late nineteenth and early twentieth centuries, new building materials, such as concrete emerged, leading to the disuse of masonry as a structural material and to a growing specialization in concrete constructions. On the other hand, there has been a progressive loss of specialization and knowledge regarding traditional construction techniques, resulting in errors of intervention. In the process of rehabilitation there are many great challenges, and a correct analysis of the building is essential, because it will prevent making irreversible errors that could jeopardize the built heritage.

One of the main requirements in the rehabilitation of old buildings lies in the reinforcement of masonry in order to improve its behaviour to seismic actions, leading to the investigation of new techniques and reinforcement materials. Depending on the type of structural anomaly found, different reinforcement techniques may be applied. Reinforced plastering is one of these techniques when applied as a structural reinforcement solution and was the object of study of the present dissertation.

1.2 OBJECTIVES AND METHODOLOGY

Over time, with the evolution and findings of new construction materials, there are several solutions of reinforced plaster that combine different reinforcements and mortars. In addition, the reinforced plaster technique can be applied for different purposes, and there is a need to evaluate which materials are most suitable for each building, depending on its purpose. These constraints with the lack of theoretical and experimental studies that accompany the evolution of the technique, have created a certain lack of knowledge and discrepancy on the part of the experts of the area, regarding what consists the solution of armed plastering. Therefore, one of the main objectives of this work is to collect the opinions of specialists in the area of rehabilitation, regarding the technique of reinforced plaster and the analysis in case studies, namely rehabilitation works.

This work focuses essentially on the study of the technique of reinforced plastering applied as reinforcement for the walls of old buildings. For a better understanding of the technique it is important to provide a framework and identify the different reinforcement solutions. This is a technique that essentially comprises two materials, the coating mortar and the reinforcement armor. Considering the great diversity of types of mortars and reinforcement possible in the reinforced plaster, it is essential to make a survey of the different materials used, the various solutions, as well as some of the associated characteristics and constraints.

2 OLD BUILDINGS WALLS – REINFORCE TECHNIQUES

Old buildings are those that were built prior to the appearance of constructions that used reinforced concrete as the dominant structural material. These are all those whose different constituent elements use traditional techniques and materials that have origin in the Roman tradition. The rehabilitation of old buildings has become increasingly important due to the need to preserve the architectural heritage, but also because it has become a very interesting activity for builders and designers. The interventions related to the rehabilitation of buildings needs a careful analysis of existing pathologies, seeking to know their origin, based on the fundamental principles of rehabilitation: durability, compatibility and reversibility (Appleton, 2011).

In general, the walls of old buildings can be classified according to their function. There are two types of different walls: strong walls or master walls and partition walls. Resistant walls or masonry walls are those which, given their geometrical and mechanical characteristics, make a decisive contribution to the stability of the building for vertical loads (usually of a gravitational nature) and horizontal forces of a random nature (winds and earthquakes).The walls with resistant capacity that define the great divisions or main divisions, are mostly in stone masonry. The partition walls only have the function of dividing the interior of the building. However, in the *Pombalina* construction the partition walls also had a structural function. This type of walls does not directly receive the vertical loads, however, because there is an interconnection of

this with other elements, floors and roofs, a very significant contribution will occur for the general locking of the structure (Appleton, 2011) (Pinho, 2000) (Pinho, 2011) (Barrell, 1997).

In Portugal, the construction technique has undergone changes over the years, mainly after the great 1755 earthquake that destroyed the whole of Lisbon. After this event, there was the so-called *Pombalina* construction that was constituted by an anti-seismic construction system, the *Pombalina* cage. In the *Pombalina* construction, the sturdy masonry walls (interior and exterior) are reinforced by a wooden framework consisting of a set of vertical, horizontal and inclined pieces, properly interconnected, forming the "crosses of Santo André", constituting a system with large stability. On the inner walls this frame is called the *Frontal*, but this name can also be applied to the wall itself. In the *Frontals*, the "crosses of Santo André" are involved in masonry of massive brick, ceramic fragments or irregular stone mortar of lime (figure 1).These walls have thicknesses between 15 and 22 cm (Appleton, 2011) (Pinho, 2000).

In this type of construction, the partition walls are of noggin wall having a thickness inferior to the *Frontal* walls (between 10 and 12 cm).This type of walls are constructed by nailing a lath on boards placed on top, protrusions, on both faces, the set being lined with sand and lime mortar. The type of partition wall most used in these constructions is the one of a standing plank to the top, constructed using plank boards that are fixed on the beam of the floor and of the ceiling and with plastering on the lath. The raised board noggin walls exhibit a great constructive quality (Pinho, 2000) (Pires, 2013). In Figure 1 an example of a sturdy stone masonry wall, a front wall and a raised board noggin wall is shown.

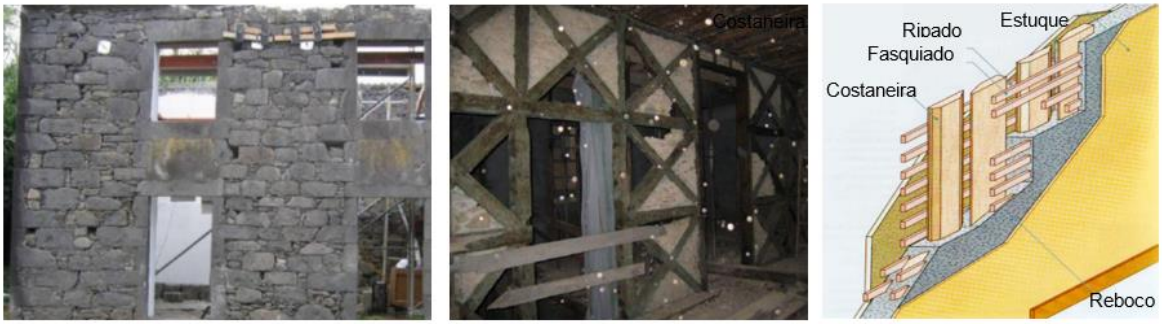


Figure 1 - (i) stone masonry wall ; (ii) frontal wall - Cruz de Santo André detail (Appleton, 2010); (iii) board placed at the top noggin wall (Appleton, 2011)**.**

The identification of the anomalies is very important to decide the appropriate type of intervention to adopt. Anomalies in old buildings can be addressed in various ways, by identifying their direct or indirect causes or by approaching building elements. The main anomalies that occur in the walls, in the masters as in the partitions, are cracking, disintegration and crushing. When an intervention of an old building is carried out, there is always a disturbance of its equilibrium (principle of minimum intervention). The level of intervention must be the minimum necessary to achieve the defined objectives. The intervention in old

buildings can be carried out at several levels, always depending on the assumptions and constraints present in each case. In order to extend the useful life of a building it is important to carry out conservation actions that include regular maintenance operations, including cleaning, minor repairs and paints. Preventive processes should always be the first option to avoid future anomalies (Roque, 2002) (Appleton, 2011) (Henriques, 1991).

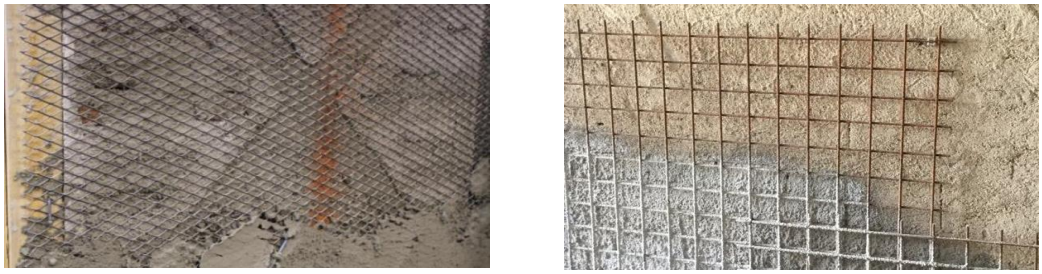
There are currently many structural strengthening techniques for older buildings. The main reinforcement techniques applied in old building wall interventions are the injection of grout, replacement of degraded material, joint reclosing, re-wrapping, prestressing, cross wall confinement, reinforcement with FRP composite materials and reinforced rendering.

3 REINFORCED PLASTER

The application of reinforced plastering corresponds to one of the techniques of reinforcement of masonry walls more commonly used today. This solution is used in masonry structures that are in good condition but that lack of anti-seismic protection, of better mechanical properties and that have high superficial degradation. Its application allows the increase of the ductility (deformation capacity), an improvement of the behavior to the horizontal actions, the increase of the bearing capacity, the control of the cracking, as well as the improvement of the connection between walls and the connection between walls and the pavement (Roque, 2002) (EU-India Economic Cross Cultural Programme, 2006) (Sofronie, 2005).

The technique of reinforced plastering consists of the application of a layer of coating mortar on the existing wall, generally with thicknesses between 2 and 3 cm, together with reinforcing armor. Reinforced plaster can be applied as a protection technique and not a reinforcement technique. In this case, the reinforcement used is only for the purpose of controlling the cracking by retraction of the coating mortar. It is usually used as reinforcing plaster, welded steel or distended metal grids (figure 2), polymer networks and fiberglass grids, which are fixed to the wall by means of small nails, metal connectors or fasteners, in order to guarantee to the wall of the masonry. The reinforcement may be applied to one or both sides of the wall, in the latter scenario it is preferable that the nails cross the wall, in order to confine the same. Since it is a technique that essentially combines two materials, the coating mortar and the reinforcement plaster, it is important to know the various solutions and which are best suited to each specific case (Manzoni et al, 2008) (Sofronie, 2005).

The types of mortars most used to coat old buildings are: cement mortars, hydraulic lime mortars, bastard lime mortars and cement, air lime mortars, aerated lime mortars with pozzolans, brick feet and other additives minerals, pre-dosed mortars. The types of reinforcement used in reinforcing walls of old buildings are steel grids, polymer grids, fiber grids.



(i) (ii)

Figure 2 - (i) Distended steel mesh; (ii) Welded steel mesh.

4 FIELD WORK

The methodology used in the field work consists of interviews with specialists in the rehabilitation area who throughout their professional career worked with the technique of reinforced plaster (through projects, studies or in the field work), and in the search and analysis of rehabilitation cases, in which the construction process includes the application of the technique of reinforced plaster.

4.1 INTERVIEWS

The interviews have as main objective the knowledge of the opinion of each interviewee regarding the technique of armed plastering. There were some questions about the technique, however, there was an openness for the interviewees to approach the subject in whatever way they preferred, allowing the subject to be explored in different ways and each interviewee transmit their ideas and opinions freely, not focusing only on the questions. Several interviews were carried out with Civil Engineers who were currently working in the area, and the interviewees are the following:

- Interview with Engineer Luís Mateus;
- Interview with Engineer João Farinha and Engineer Bruno Monteiro (visit to the company Htecnic);
- Iinterview with Engineer Vasco Appleton (visit to the company A2P);
- Interview with Engineer Rita Bento;
- Interview with Engineer Eduardo Monteiro.

4.1.1 FINAL COMMENTS

Five interviews were made with Civil Engineers with different careers and professional positions. The number of interviews carried out does not allow obtaining a generalized opinion of all the population that works, directly or indirectly, with the solution of armed plastering. However, it is only through interviews that one can see, comparing the opinions of each interviewee, that there is sometimes inconsistency regarding some aspects related to the technique of armed plastering.

The general opinion of the interviewees is that this technique is mostly applied in the rehabilitation of old buildings. Almost all the interviewees point to the importance of evaluating the compatibility between the solution and the support where it is applied, as well as the structural compatibility between the chosen reinforcement and the mortar. It is common to choose the type of mortar first and then to choose the reinforcement. The mortars most used in old walls, considering the compatibility and depending on the characteristics of the support and the required functional requirements, are those that use aerial lime or hydraulic lime. The feature that generated more controversy derives in the main purpose of the technique. Most of the interviewees agree that this technique is essentially used as structural reinforcement of walls, however, Engineers João Farinha and Bruno Monteiro argue that the technique should only be applied as a protection solution of the facing and that the introduction of a mesh´s sole purpose is to prevent cracking by retraction of the mortar. This opinion is not in line with that of most respondents as regards to the main purpose of the technique.

4.2 CASE STUDY

The main objective of the study cases is to analyze the constructive process of the reinforced plaster technique, taking into account the type of building or work of art and the purpose of the solution, in order to compare the work in the field with the theoretical contents analyzed in the previous chapters. The study of the various rehabilitation works focuses mainly on the analysis of the technique of armed plastering, however, it is also sought to frame and characterize the work and describe the main anomalies verified. We gathered information for the analysis of four cases of studies involving the application of the technique of reinforced plastering in rehabilitation works, being the following:

a. Rehabilitation work on Rua da Salitre, N.º 191 – Lisboa building;
b. Rehabilitation and reinforced work on Ribeira da Machada – Lagos bridge;
c. Rehabilitation work on Calçada de Santana, N.º 199 – Lisboa building;
d. Rehabilitation work on Rua da Salitre, N.º 134, 136, 136ª e 138 – Lisboa building.

4.2.1 CRITICAL ANALYSIS

Three of the case studies analyzed refer to the rehabilitation of old buildings. In these buildings the general degradation of the walls to be maintained and reinforced was low and therefore the intervention solutions adopted are not to demolish the walls but rather to reinforce them with solutions such as reinforced plaster and reinforced micro-concrete.

For a better comparison and interpretation of the various solutions, in table 1 is the description of the type of existing walls and the adopted plaster solution in the analyzed buildings.

Table 1 – Reinforced plater solution applied in the case studies analyzed.

Bulding	Type of wall	Rehinforced plaster solution adopted			
		Method of application of the mortar	Mortar	Armor	Thickness
Application of the reinforced plaster technique as structural reinforcement					
(1)	Peripheral and interior walls in ordinary stone masonry	Projection	Coarse mortar + mortar based on cement	Electrically welded network A500 NR SD	3 cm
	Interior walls of frontal and noggin				
(2)	Peripheral walls in ordinary stone masonry in need of a higher resistant capacity		Industrial mortar (AE)	Distended Steel Network L62 T2025 (2,8 kg/m^2)	10 cm
	Peripheral walls in ordinary stone masonry in need of a less resistant capacity				5 cm
(3)	Peripheral walls in ordinary stone masonry and most of the front walls of the ground floor.		Industrial mortar (AE)	Distended Steel Network L75 T3050 (6,5 kg/m^2)	5 cm
	Peripheral walls in ordinary masonry and interior walls of front of the 1st and 2nd floor			Distended Steel Network L62 T2025 (2,8 kg/m^2)	3 cm
Application of the reinforced rendering technique as a coating with the introduction of an armor to control the cracking of the mortar					
(4)	Arch in masonry of sandstone blocks mortar with lime and filling in stone masonry	Projection	Hydraulic lime	Glass Fiber Network (PVC)	3 cm

Legend:

(1) - Rua da Salitre building, N.º 191;

(2) - Calçada de Santana building, N.º 199;

(3) - Salitre building, N.º 134,136, 136ª, 138;

(4) - River over Ribeira da Machada.

The analysis of the three buildings focused only on reinforced plaster walls, except in the building of Rua da Salitre, N.º 191, which also analyzed the walls reinforced with armed blades of micro-concrete. In this building, the same reinforcement and the same constructive process were used in the solution of reinforced plaster and reinforced micro-concrete, differing only the type of mortar used and the thickness of the blade. Because they were similar solutions, it was decided to analyze them both. All reinforcement solutions analyzed had the objective of strengthening the structural level of the wall. In the rehabilitation and reinforcement of the Bridge over the Ribeira da Machada, a plaster was applied whose main function is the coating and protection of the stone masonry.The fiberglass net was incorporated in the plaster in order to reduce the cracking of the mortar due to the retraction of the mortar during the drying process.

The analyzed buildings have an identical structure, and are generally composed of peripheral walls of stone masonry and of interior walls of frontal and noggin walls and sometimes stone masonry. The level of degradation of the walls in general was low and therefore the intervention solutions adopted did not go through the demolition of the walls, but reinforcing them with armed blades of concrete, micro-concrete or plastering. The application of a solution of reinforced plastering in old buildings or in works of art presents several challenges in its adoption. Usually the greatest challenges in this type of construction arise due to the need to preserve its architecture and possible patrimonial value.

Regarding the method of application of the mortar, there is a preference for the projection through mechanical means and the realization of monolayer industrial plasters. These methods allow a high speed execution of the plasters compared to the manual application and the accomplishment of traditional plasters. Cimpor´s (AE) shell mortar was applied in the "Calçada de Santana" Building, N.º 199 and Salitre Building, N.º 134,136, 136ª, 138, directly on the support, as monolayer plaster, replacing the three traditional layers: slab, base layer and finishing layer. This mortar allows the execution of layers of plaster with about 2 cm of thickness and the realization of several layers.

At the Rua de Salitre building, N.º 191, the reinforced plaster and reinforced micro-concrete were applied to only one side of the wall to allow the support to "breathe". In this building, in the walls where the plaster solution did not allow to obtain the necessary structural reinforcement, blades of armed micro-concrete were applied. In the rehabilitation of the Calçada de Santana Building, Nº. 199 and the Salitre Street Building, N.º 134,136, 136th, 138, in some walls was applied the solution of reinforced plaster with a thickness well over 3 cm, with about 5 and 10 cm. These thicknesses sometimes resemble those seen on the blades of armed micro-concrete. Also used in these two works was a plaster of cement of Cimpor. The high thicknesses verified come from several reasons, namely the need to achieve a greater resistance in the wall, which would not be obtained in thicknesses of 3 cm, and to ensure the steel frame covering, avoiding the penetration of water, CO2 , and chlorides that cause corrosion of the armature. The fact that Cimpor 's shell mortar has a compressive strength (28 days) greater or equal to 6 MPa, a value that is much lower than that observed in Secil' s plaster mortar applied in the building of Rua da Salitre N.º 191,

which presents compressive strength (28 days) greater than or equal to 20 MPa may be another reason for the high thicknesses observed.

The solutions with blades of reinforced micro-concrete are not the most suitable for the reinforcement of old walls, due to the aspects related to the incompatibility of the mechanical performances (at the level of the interior tensions of the materials), the lack of permeability to water vapor and the significant difference between the rigidity of the pre-existing materials and the repair materials, with the use of mortars such as AE containing in its composition hydraulic lime being preferred. Therefore, in order to ensure the necessary reinforcement and compatibility aspects, reinforced plastering solutions consisting of lime-based mortars and applied with a thickness of more than 3 cm are chosen. This solution turns out to be the compromise between blades of micro-concrete, which is too impermeable for this type of walls, and plaster of lime, too permeable and weak for the reinforcement that is intended. In the rehabilitation of Rua da Salitre Building, N.^{o} 191, a blade of armed micro-concrete was applied to the walls whose required reinforcement level was not obtained with a reinforced plaster solution, using the same reinforcement in these two solutions. The applied reinforced plaster was about 3 cm thick. Given this, it can be noticed that in the rehabilitation of walls of old buildings, there is a need to obtain solutions of reinforced plaster capable of achieving an increasingly structural performance, in order to replace solutions that are less compatible with previous supports.

5 FINAL CONCLUSIONS

Portugal is currently experiencing great growth in the rehabilitation of existing buildings. In view of its economic advantage in relation to the market for new buildings, which is currently saturated, and the urgency of intervening on the old construction (at structural and aesthetic level), there is a need for rapid rehabilitation works. The technique of reinforced plaster is very efficient in reinforcing masonry walls of old buildings. The application of this technique to the walls of old buildings has the purpose of avoiding the emergence of generalized cracking due to the retraction of the coating mortar, when applied as non-structural reinforcement, or to confer an increase of ductility (deformation capacity), an improvement of behavior to the horizontal actions and the increase of the carrying capacity, when applied as structural reinforcement. In any case, in order to obtain the desired performance of the technique, an analysis of the chemical and physical compatibility between the reinforcing material and the mortar is required.

For the accomplishment of this work a review of the literature was carried out which encompassed the various measures of reinforcement of walls in the rehabilitation of old buildings and the detailed characterization of the technique of armed plastering. After this analysis, we sought to complement the bibliographical research with interviews with specialists in the area of rehabilitation and information gathering regarding rehabilitation works where reinforcement solutions were applied with the technique of armed plastering.

Throughout the bibliographic research, the type of support of the old stone masonry buildings was characterized and the main anomalies verified were identified. Considering the type of constructions under analysis and the type of anomalies most frequently observed, the main reinforcement techniques were identified considering the constraints inherent in each of them. A detailed characterization of the technique of reinforced plastering was performed where the various types of mortars and reinforcement armors were identified, as well as some of the application techniques. The most commonly used types of mortars are cement mortars, hydraulic lime, aerial lime or a combination of these that must meet various functional requirements of the plaster. Today there is a preference for the use of industrial mortars. The main reinforcement armors used are steel grids, polymer grids and fiber grids. When rehabilitating an old building, the level of intervention must be the minimum necessary to achieve the defined objectives. The compatibility, the reversibility and the durability of the solutions adopted should be ensured whenever possible.

The interviews allowed to collect several opinions of Civil Engineers regarding the technique of armed plastering. Despite the low number of interviews, it is possible to notice that in some aspects there is a divergence in the opinions gathered. The various interviewees affirm that the technique is mainly applied in the rehabilitation of old buildings, and it is important to carry out a compatibility analysis between the different existing materials and the materials to be applied. Regarding the purpose of the technique, there is also divergence in the different opinions obtained. In general opinion, the purpose is mainly to reinforce the walls at the structural level, however, there are those who argue that the solution should not be carried out for this purpose and that its purpose is only to control the retraction of the mortar, preventing its cracking. This divergence comes mainly from the evolution of the technique. For some specialists in the field of civil construction, this evolution did not have the desired technical monitoring, giving rise to solutions that in their opinions should not be applied, namely, the technique of reinforced plastering as structural reinforcement of the walls.

Comparing the methods used in the different case studies of buildings, with the contents of the bibliographical research, there is some lack of consensus, for example in the thickness of the applied blades. In two of the analyzed cases, blades of reinforced plastering with 5 and 10 cm of thickness are applied. The thicknesses observed arise from the need to obtain a reinforced rendering solution which has a higher strength and which guarantees the necessary recoating, thus replacing solutions that present this level of performance but which are less suitable due to the problems related to compatibility between pre-existing materials and repair materials as for example the blades of armed micro-concrete.

The conclusions presented were based on the bibliographical research carried out, sought to be diversified and complete, and may not consider the entire theoretical context. The information collected during the interviews and the information collected from the case studies is dependent on the information that was made available.

6 BIBLIOGRAPHIC REFERENCES

Appleton, J. (2010). *Rehabilitation of old buildings: an sustainable choice (in Portuguese).* II Quercus Conference – Sustainable architecture.

Appleton, J. (2011). *Rehabilitation of old buildings - pathologies and intervention techniques (in Portuguese).* 2ª Edition, Orion Editions, november, 2011.

Barrell, C. (1997). *Characterization of The Mechanical Behaviour of Masonry.* Structural Analysis of Historical Construction. Possibilities of Numerical and Experimental Techniques. Edited By Roca, P., González, A., Mari, A.; Onate, E., International Center for Numerical Methods in Engineering (CIMNE), Barcelona, 1997.

EU-India Economic Cross Cultural Programme. (2006). *Identification of Strengthening Strategies.* Inprovoding the seismic resistence of cultural heritage buildings, october, 2006.

Henriques, F. (1991). *The Conservation of Built Historic Heritage (in Portuguese).* Memory nº755. LNEC, Lisbon, 1991.

Manzoni, E., Dusi, A., & Mezzi, M. (2008). *Polymeric grid for a cost effective enhancement of the seismic perfomance of masonry buildings.* World Conference on Earthquake Engineering, Beijing, China, 2008.

Pinho, F. (2000). *Walls of Old Buildings in Portugal (in Portuguese)*. Collection buildings, nº 8, LNEC, Lisbon, 2000.

Pinho, F. (2011). *Constructive and functional aspects of partition walls in traditional construction (in Portuguese).* Walls 2011 - Seminar “Partition Walls: Past, Present and Future”, 2011.

Pires, A. (2013). *Analysis of partition walls and structural reinforcement measures; Numerical study (in Portuguese).* Dissertation for obtaining the Master's degree in Civil Engineering in the specialty of Structures, FEUP, Porto, 2013.

Roque, J. (2002). *Structural Rehabilitation of Old Masonry Walls (in Portuguese).* Dissertation for obtaining a Master's Degree in Civil Engineering, University of Minho, Braga, 2002.

Sofronie, R. (2005). *Application of Reinforcing Techniques with Polymer Grids for Masonry Buildings.* (LNEC, Ed.). Report nº5 of the RTN CASCADE, LNEC, 2005.