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Structural Rehabilitation of Old Buildings

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Preface

During the end of the nineteenth and the beginning of the twentieth centuries, the centers of many urban areas suffered important transformations that were responsible for the demolition of a considerable number of constructions, giving place to wider open areas and avenues. Also, new agglomerates of buildings were created outside the city centers, leading to the abandon and degradation of a considerable number of constructions. In reality, the way constructions are understood has modified over the years, following the changes in peoples' lifestyle and demands. In some cases this made people to move to new and modern areas, in other cases to intervene on the existing buildings, or to demolish and substitute them with new ones.

Intervening on an old building is, therefore, a matter that concerns social, economic, and cultural issues, which may assume different weights depending on the available funding, the knowledge and sensibility of the owners and technicians involved, the location and importance of the construction, the perspective of the authorities, among many other issues. The gathering of these data will constrain the procedures and techniques involved on the intervention of an old building, which, however, should always aim, in parallel with other concerns, the accomplishment of structural safety and the usage or service requirements, but without ignoring the particular value of the building.

Unfortunately, in the past many interventions on existent buildings have been inadequate in terms of the protection of their materials and constructive systems. An extreme, but paradigmatic example is the demolishment and substitution of the whole interior of the buildings, substituting it with new structural systems, just preserving the façades. Such types of interventions are quite invasive and ignore the constructive typologies and techniques that characterize the buildings. Moreover, they may introduce different materials and systems, not always sufficiently tested and known and that can create physical, chemical, and structural incompatibilities with those already existing in the buildings. In some countries, the lack of specific codes for the rehabilitation, enforcing the use of codes aimed for the design of new constructions, has strongly contributed to these results.

Actually, there are international recommendations and charts describing principles that should be respected when intervening on old constructions. They refer to some characteristics the interventions should aim; in particular, they should be low intrusive, reversible, and compatible with the preexistences. Although they are not always easy or possible to be fully respected, a growing effort has been made to converge to interventions closer to these principles, which can be only achieved with a proper knowledge of the materials, structural systems, and construction techniques used in the constructions. In fact, the lack of knowledge is, probably, the most important aspect that leads to the disrespect of the built heritage. It leads to the lack of confidence on old materials and induces technicians to look to old constructions not as something capable of sustaining the current needs of people, providing that proper interventions are made, but as something meant to be replaced by a new construction made of materials they know and rely on better, namely concrete and steel. Such perception often makes technicians to propose solutions on old constructions that lead to invasive and barely reversible interventions, and eventually to the near total destruction of the existing building.

Following this purpose, the book highlights the most important aspects involved in the characterization and understanding of the behavior of the most common structural systems and materials that are part of old constructions. It starts with the description of the structural systems of traditional buildings, referring to the most common structural elements and to their influence on the overall behavior of the construction. The subsequent chapters go more in detail in the structural elements and characterize, separately, the main elements that constitute an old building, namely: masonry walls either made of earth, bricks, or stone, timber and composite walls made of timber and infill material, and timber structural floors and roofs. In the book is also included a chapter dedicated to reinforced concrete structures, probably the most important structural material that, by the beginning of the twentieth century, progressively substituted the previous materials, being used in many constructions from that period on. Each of these chapters describes, with different levels of detailing, the materials, the construction procedures, the mechanical properties, the mechanical behavior, the damage patterns, and the most probable collapse mechanisms. Some of the chapters also present common or pioneering intervention measures applied to the repair and/or strengthening of structural elements, referring to their applicability and expected results.

To conclude, the editors believe that the book gives important information about the characterization of old buildings, helping the reader to have a better understanding of the behavior of these constructions and facilitating information that may help in the development of more precise and correct interventions, more in agreement with their original characteristics and cultural value.

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Construction Systems

Alice Tavares, Dina D'Ayala, Aníbal Costa and Humberto Varum

Abstract Understanding the character of a construction system is the base of any pre-evaluation process to support correct, sustainable rehabilitation decisions. For the uniqueness of a building lies partly in the preservation of its construction system, this testifies to the history or culture of a region with its environmental approaches. This chapter presents an overview of important influences as through treatises and a sample of traditional construction systems including other engineered solutions from the eighteenth century. The evolution of system characteristics and the systems' relationships with seismic regions or routes of dissemination is discussed, with archaeological and published examples. The wall-to-wall connections of antique systems are also emphasised to interpret the links between different traditional construction systems appearing all over the world, for the improvement of box behaviour. The debate around the definition of construction systems and their division in categories is also included to emphasise the particular understanding of the vernacular architecture.

KeyWords Constructions systems • Written sources • Treatises • Structural historical evolution • Structural vulnerabilities • Connections • Vernacular architecture

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1 Introduction

Understanding how a construction system is assembled is the first step towards an insight of how it works, how it behave not only for the loadings and actions it was designed or conceived to withstand, but more importantly towards the ones that it needs to endure in time and for which no provision were made at its inception. This is particularly the case for traditional construction systems exposed to seismic action. The first requirement is a robust definition of what is intended for traditional construction in this context *versus* industrialized systems, as the former and its structural behaviour is the object of this book. The history of architecture and the built environment is often portrayed as a two-track path where formal and grander architecture has followed a route separate from the ordinary and vernacular construction with modest reciprocal influence. A review of historic treatises, from Vitruvius' and Alberti's to the some of the eighteenth century authors more specifically interested in the seismic resistance of contemporary construction, proves not only the deep contamination of the two areas of architecture (the courtly and the ordinary) in seismic prone regions, but also the continuity of thought between architectural design solutions and technical solutions, resulting in concerted choices in each part of the building resulting in a more resilient construction system. The enhanced seismic performance of masonry construction in which perpendicular walls are well connected to provide a box behaviour is a well proven concept in seismic engineering and one that informs most repair and retrofitting solutions proposed in modern design seismic codes and guidelines. A comparative analysis of a number of historic and vernacular construction systems, from diverse seismic prone regions and diverse age shows that this is a fundamental construction detail that found robust solutions well before the development of seismic engineering. The necessity to provide a construction system with sturdiness together with flexural capacity and ductility has led in the past to several more or less "vernacular" composite solutions.

Finally, in this chapter are discussed historical and architectural aspects related to the different construction systems studied in this book, with particular emphasis on traditional systems, but retrofitting solutions for the strengthening of buildings from the Modernism style are also presented.

2 Definitions of Construction System

The evolution of a construction system over the centuries is the result of a process of adaptation to climate, to geographical location and soil conditions, but is also influenced by past and present cultural background, economic considerations, taste and fashion. However, the progressive industrialization of methods of construction and the growing requirement from society for quality controls, assurance in the construction practice and in building codes has fostered increased control over the characteristics of materials and components used and over the structural and environmental building performance. The concept of construction system has gradually become more closely linked to the definition of an industrial process, as shown by the following set of statements stretching over the past 40 years. A construction system is:

- a "combination of structures involving organisation, technology and design process" [1] (Schmid T. and Testa C.);
- a "combination of production technologies, component design and construction organisation" [2] (Warszawski A.);
- a concept that "must only be applied to identify advanced industrialised processes of construction, which can be divided into three categories: (i) the design process and the management and control of construction methods; (ii) the technical subsystems such as structure, roof, walls, etc.; and (iii) the full range of activities involved in the production, construction and maintenance of all the specific components" [3] (Sebestyén G.);
- a concept that "encompasses the activities required to build and validate a new system to the point that it can be turned over for acceptance. This presumes an emphasis on the design process to ensure that technical solutions are based on the functional and operational requirements captured during the analysis phase, which includes a series of tests of each component to verify the entire system" [4, pp.129] (NYS ITS).

These definitions reveal the underlying assumption that a construction can be considered a system only if the foreseen performance of each of its materials and components follows a continuous process of appraisal and control from the planning through to the design and the construction phases, and eventually its use.

As correctly pointed out by Sebestyén statement [3], difficulties may arise when such definitions are applied to pre-industrial or vernacular architecture. Indeed the production processes involving these construction systems were conditioned by diverse social structures and cultural background. The production of construction well into the twentieth century was still based in many regions of Europe on the organisation, delivery and application of different crafts within the building site; crafts learned by apprenticeship and oral communication and whose quality control relied conspicuously upon the pride, skill and sense of ownership of the process by the craftsmen. A process which entailed the repeated application of "rules of thumbs" and procedures with well-established performance, and which saw over the years relatively modest variations and improvements to adapt it to different environmental and economic condition and client demand.

Not withstanding the differences in the mode of production of traditional versus industrialised construction, the requirements that both classes of buildings are expected to fulfil are the same, as first formally stated by Vitruvius: environmental comfort, aesthetic comfort, and durability through robustness. Any system is by definition made up of different components with different shapes, functions, materials and crafting. However, for their optimal performance, it is important to guarantee not only the quality of all materials and their compatibility but also the correct design and dimensioning for each component to fulfil its function and the correct type of connections between elements and components to ensure that the system works as a whole.

The connectivity between elements and components fulfilling different functions is a critical aspect for the ability of the system to withstand the actions a building is designed for, and most importantly, for its resilience against unforeseen environmental demands. In particular such connectivity can be identified as follows:

1. The foundations and their relation with the characteristics of the soil;
2. The connection between the upper structure and its footing, including waterproof layers;
3. The connection between vertical elements;
4. The connection between vertical and horizontal elements;
5. The connection between vertical elements and the roof; and.
6. The connection and correct position of non-structural elements such as chimneys, balconies, windows, doors and other elements with respect to the overall layout and the position of the structural elements.

These concepts have been codified since Roman times in the western world (Vitruvius, De architectura libri decem [5, 6]) and since a similar time in the Asian world (although Yangzi Fashi, the earliest surviving treatise of Chinese architecture was written by Li Jie during the mid-Song dynasty 1097–1100, it is a re-visitation of older pre-existing texts [7]) and represent the basis of any good construction, be it vernacular or formal architecture. To accomplish the Vitruvian "firmitas", knowledge of the mechanical behaviour of materials and components and of their expected as opposed to the achievable performance is essential. For traditional construction this knowledge was developed empirically and through the act of building and it was transmitted from generation to generation by the systems of apprenticeship. It constituted nonetheless a system of knowledge to be applied to a complex system. While a minority of sources exist documenting the process of knowledge transmission in the pre-industrial construction yard (one for all Villard de Honnecurt), more information on the development of structural resilience against seismic action in historical construction and its dissemination through ages and different regions can be obtained by a comparative reading of historic architectural treatises, as outlined in the next section.

3 Knowledge Dissemination Through Treatises

As it is well known western architectural theory and treatises have their archetype in the *De Architettura libri decem* of the roman Vitruvius (30–20 B.C.) [5, 6]. According to Vitruvius two fundamental concepts relate directly to robustness: the concept of proportion as the correspondence of members to one another and to the whole, measured by means of a "fixed part" [5, pp. 196] and the concept of symmetry taken as the fundamental condition for "coherence", the result of calculated relationships where each part bears measurable relation to every other part as well as the configuration of the whole [5]. In 1452 the *De re aedificatoria* [8, 9] of Leon

Battista Alberti (1404–1472), fashioned along the same structure of Vitruvius' treatise, traces back the current construction knowledge to the observation of roman archaeological sites and defines the aesthetic value in architecture as "the unity of all the parts founded upon a precise law and in such a way that nothing can be added, diminished, or altered but for worse" [8, p. 240]. More interestingly to the present discussion, however, in the third book Alberti explains this concept in terms of construction, considering that "the whole method of construction is summed up and accomplished in one principle: the ordered and skilful composition of various materials, be they squared stones, aggregate, timber, or whatever, to form a solid and as far as possible, integral and unified structure" [9, p. 61]. Moreover such structure shall be considered integral and unified only "when the parts it contains are not to be separate or displaced, but their every line joins and matches" [9, p. 61].

This concept that unity and integrity are fundamental to structural robustness and resilience is, to the authors knowledge, further developed and applied in practice in at least two instances following destructive earthquakes in the eighteenth century: the case of the *Pombalino* cage construction system of Lisbon (capital of Portugal) used in the reconstruction of Lisbon after the devastating earthquake of 1755, and in the so called *Casa Baraccata* theorised by Milizia in 1781 and extensively used through Calabria region in the reconstruction post the destructive seismic events of 1783.

The authors of the Pombalino cage (to which a whole chapter is dedicated in this book),were military architects and civil engineers (Manuel da Maya, Eugénio dos Santos and Carlos Mardel) emphasized the needs for proportion and symmetry, but also introduced regularity and progressive standardization as essential principles to design a timber frame structure with infill materials, using the idea of a unified construction system, where the connections had a particular importance to balance and guarantee the distribution of loads in a seismic event and to prevent the collapse of the timber cage.

In 1781, 2 years before the strong earthquake of Calabria (Italy) Francesco Milizia (1725–1798) published his *Principij di architettura civile* of where he proposed a composite timber framed building infilled with masonry where every piece needed to be well connected and embedded with the others explicitly to resist seismic actions [10].

In the following sections a detailed reading of these and other contemporary sources is carried out with relevance to the list of connectivity introduced in Sect. 2. The aim is to identify the specific advice and provision contained in the treatises, on the role of each component including size and relationship among parts, and compare these with the details of historic traditional composite construction as it can be observed in seismic region nowadays. The latter will be carried out in Sect. 4.

3.1 Foundations

Alberti's in his third book (1452) provides detailed advice on soil characteristics requirements to withstand the weight of the building, including the importance of underground inspections by trench digging and wells [9] with the aim of identifying the most suitable stratum to implant the foundations the presence of underground water courses or other instances that could hinder the erection of the building [9]. For construction on marshy ground with poor load bearing capacity, he recommends the use of inverted stakes and piles covering twice the surface footprint of the proposed wall, establishing the length of the piles no less than one eight of the planned height of the building and with a diameter no less than a twelfth of their length. Moreover he advises on ventilation of basements and foundations to prevent rotting [9]. Very specifically he indicated that the foundation should be made of solid stones and that this should be built up to a level of 0.30 m off the ground to prevent rising damp and rain erosion. This assumption is later present in other treatises as in the Vivenzio's, who advocated the use of a lower stone platform bigger than the perimeter of walls, considering the separation between foundation and base soil [10]. These concerns were wider disseminated for earth constructions and even timber-framed constructions in many European regions.

Pirro Ligorio (1513–1583) in his report of the long Ferrara earthquake (1570–1572)—*Libri di diversi terremoti*—specifically stresses the importance of sound foundation to guarantee the stability of the building in a seismic event [11].

Milizia in his treatise voices wider concerns, more akin to a comprehensive hazard assessment from the salubrity of the area to its seismic hazard from exposure to floods, to ground depressions and landslides, soft soil and other forms of unstable ground [12].

These particular concerns involved the shape and desired characteristics of the foundations of walls or of columns. Alberti considered a detachment between structure and foundation despite include the plinth as an element of the foundation [9]. Also, the discontinuity of the wall foundations through the use of arches was addressed for pillars or columns for particular grounds characteristics [9]. The capacity of the ground to withstand the intended load of the building was also highlighted [9]. For the stability of the structure he recommended foundations wider than the thickness of the wall [9], this is also present in the 18th century treatises as of Bélidor (1754), discussing also the correct depth of foundations [13].

3.2 Walls and Openings

Alberti treatise (1452) emphasized the needs of guarantee that the walls connect perpendicularly and complete, as much as possible unbroken from the ground to the roof and the placement of the openings in a way that would maintain the strength of the structure. For this reason he also proposed to keep windows away from the corners, mentioning that in ancient architecture it was custom "never allow openings of any kind to occupy more than a seventh or less than a ninth of walls surface" [9, p. 27]. The proportion of the openings was dependent on the distance between columns. Moreover he recommended the use of arched openings considering this the most suitable and durable form, however taking in account to "avoid having an arch of less than a semicircle with one seventh of the radius added"[9, p. 30], i.e. a raised profile. He stated that this was the only one that does not require ties or other means of support, mentioning that "all the others, when on their own and without the restraint of ties and opposing weights, seemed to crack and give way" [9, p. 31]. Alberti considered that attention should be applied to the wall around the openings, which should be "strengthened according to the size of the load that should bear" [9, p. 71].

Recommendations about corners, arches and openings were also present in the treatise *Trattato del Terremoto* of 1571 by Stefano Breventano (1502–1577) [10], while Antonio Buoni in his book *Dialogo del Terremoto* reported detailed observation of damages to arches after the Bologna and Ferrara earthquake [11].

In the *Pombalino* constructions built from 1756 special attention was given to the regular distribution and dimensions of the openings and the corners, obeying to official design plans of the façades. In 1758 a regulation was published limiting the height of the building and imposing restriction on element jutting out of the façades [14]. The design plans of the interior proposed also regular dimensions with standardized measures for the timber, stone and iron elements. These allowed the prefabrication of the elements in the outskirts of Lisbon, which were transported to the Baixa's construction sites only when needed it [14]. Such procedure allowed cost reduction for materials, production and workmanship [14]. The military civil engineer Manuel da Maya in a first proposal considered a restriction on the height of the buildings just for two floors. However, due to the social pressure imposed by necessity of housing and construction profit, the allowable height was extended to 4–5 floors, making the need for a seismic-proof solution all the more pressing [14]. The allowable height of the building was also correlated to the width of the street, to reduce the risk of people being injured by debris falling in the street from the buildings during an earthquake and to maintain a safe area to rescue people and to allow circulation in the immediate aftermath of a destructive shock.

Also Milizia (1781) establishes similar correlations between the height of the building and the width of the street. He proposed that dwellings built along principal streets could have three floors while along secondary streets no more than two floors [12]. While already Scamozzi (1548–1616) in the 16th century had advised that a building should be no taller than the width of the street is built along, Milizia considered that it was more appropriate to adopt a proportional measure [12].

After the 1783 Calabria earthquake an seismic-proof solution for residential buildings conceived by the architect Vincenzio Ferraresi was shown in the treatise of Giovanni Vivenzio *Istoria e teoria de tremuoti* 1783 [15]. This had a specific urban connotation as it foresee a two storey building flanked by two single storey buildings with the role of propping the taller building. Vivenzio argued that such solution was good because in this way at street corners the height of the construction will be smaller, less vulnerable and with lower risk of obstructing the two streets [16]. His consideration were purely static, and he overlooked the possibility that buildings of different height would have diverse natural periods and stiffness's and could damage each other through pounding. In 1784 the Istruzioni Reali of the Borboni's Government of the reconstruction of Reggio Calabria, included the proposals of Vivenzio and established the maximum height of buildings at approximately 30 palms [17, 18]. In large streets and squares were allowed buildings with the addition of a mezzanine floor with no more than 9–10 palms [17].

3.3 Corners and Wall Materials

Alberti considered each corner as "half of the whole Structure" and the point of the building where any damage or decay would start [9]. So he stated that corners throughout the building need to be exceptionally strong and be solidly constructed [9]. Alberti emphasized the ancient practice of considerably thickening the walls at the corner by adding pilasters to reinforce that area "to keep the wall up to its duty and hinder it from leaning any way from its perpendicular" [9]. In addition he underlined the need to use a system of quoins, stones longer and of the same thickness of the wall so as to avoid filling, that would extend into each of the walls at the corner in alternate courses that could support the remaining panelling [9]. Most importantly, in relation to the connections of façades of adjacent buildings along a street he states: "Stones left every other Row jutting out at the Ends of the Wall, like Teeth, for the Stones of the other Front of the Wall to fasten and catch into" [9]. This attention for the construction of the corners was also present in the treatises of Bélidor [13] (Bélidor B. 1754) and Milizia (1781), who highlighted the importance of this due to the effect of loads on the corners in a seismic event [12].

Recommendations for the most appropriate use of materials in diverse parts of the construction were already present in Vitruvius and cited by Alberti. Several other treatises and books had specific chapter dedicated to materials, as the *L'Encyclopédie* [19] coordinated by Denis Diderot (1713–1784) and Jean Le Rond D'Alembert (1717–1783) whose several books were published during 1751 until 1772. This work intended to record different fields of knowledge, including information about construction practices, catalogues of construction elements and their organization into construction systems, taking into account their regional variations.

Another encyclopaedia related to the existing building typologies seismically deficient, the World Housing Encyclopaedia (www.worldhousing-net.com) is been developed by EERI with the contribution of many researchers from different countries over the past 15 years. This resource, available online, contains important information concerning vernacular traditional and modern housing construction systems in seismic prone regions of the World. The aim is to identify the specific construction elements and construction practices that render a particular system more or less prone to earth-quake damage, classifying them with respect to the EMS' 98 vulnerability scale [20].

The introduction of tie rods in specific locations is one of the measures adopted traditionally in many regions to guarantee better connection between walls and between walls and the roof or floors [21]. This measure would have a very significant effect on the vulnerability, most outstandingly for taller buildings, 4–6 storeys high, as demonstrated in a study carried out on the traditional constructions of Alfama, a district of Lisbon [22].

From the information of the treatises analysed in this chapter is interesting some specific to walls. Alberti considered in his treatise (1452) that one of the most important rules was to build the wall in level and uniform considering that any side could had larger stones and the other small ones [9]. The explanation for such measure was associated with the assumption that imposed weight put irregular pressure on the structure, in addition to the less grip of the drying mortar leaded to cracks in the wall [9]. After the Calabria earthquake (1783), La Vega presented proposals with similar concerns, mentioning references to the sizing of the stones to be included in rubble stone masonry, highlighting also the need of using a quality blend for the mortar [18]. Also Milizia (1781) emphasized the need of uniform distribution of the weight for the structural equilibrium, considering that the materials used should be of the same quality to ensure such purpose [12].

Observing the ancient constructions Alberti concluded that the infilling of the walls was based on the rule that imposed every single section of infill with no more than 1.52 m approximately without being bonded in some areas with a course of long and broad squared stones [9]. He considered this squared stones as acting as "ligatures or muscles, girding and holding the structure together and also ensured that should subsidence occur in any part of the infill, either by accident or as the result of poor workmanship, it would have a form of fresh base on which to rest" [9, pp. 72]. This construction detail can be observed in many Roman constructions, in some cases of the stone being replaced by brick layers along the wall made of thin ceramic elements. In vernacular constructions in seismic regions this form of lacing is achieved by the use of timber elements laid along and across the wall, as it will be discussed in the next section. Milizia also recommends the use of "a succession of ties made of charred olive wood, binding the two faces of the wall together like pins, to give it lasting endurance" [23, p. 45].

Another interesting statement related with different types of stone masonry is the recommendation to improve the durability of the structure. Alberti emphasized the need of each course of the whole wall be composed entirely by squared stone [9]. Nevertheless, if it was necessary to fill the gaps between the two vertical plans of the wall, must be ensured that the courses on either side were bonded together and level [9]. In addition, he recommended the use of spaced block stones, spanning across the wall connecting both vertical plans "to prevent the two outer surfaces that frame the work from bulging out when the infill is poured in" [9, p. 73]. This recommendation is used even in vernacular construction made of stone masonry, as for public buildings, dwellings and walls. It is also associated to the stability of the structure and the need to improve the mechanical behaviour of the entire wall unifying as much as possible its elements.

In relation to the infill materials, Alberti emphasized again the ancient knowledge, considering that small stones joint and bond together better than the bigger ones. For this reason he also recommended that the infill did not contain stones weighing more than 327.45 g approximately and all the materials should be carefully bound together and filled in [9], again a concern to maintain the stability of the wall.

The same concern is pointed out for the construction of the cornice, that Alberti stated again as important to bind the wall tightly together [9]. For this reason a special care should be given to the stone characteristics used in this area. Considering that the blocks should be extremely long and wide, the jointing continuous and well made, the courses perfectly level and squared [9]. The care in this particular component of the construction is justified by Alberti assuming that is a potential vulnerable area of the construction where "it binds the work together at a point where it is most likely to give way"[9, p.74], besides its function of upper protection of the wall to prevent damages by the rain. This particular aspect can be observed in vernacular architecture with stone masonry and in earth constructions with the use of stone or layers of thin tile bricks on that area, in addition to the protection of the eaves.

3.4 Roof and Protection Against Fire

The connections between walls and roof structure received particular attention in the treatise and practice of reconstruction in seismic region in the eighteenth century. The *Pombalino* cage considered specific connections involving the structure of the roof. Lisbon regulations at the time (from 1756) also forbid any element protruding from the roof, allowing in a first stage only the kitchen chimney. Similar restriction was imposed in Calabria (Italy) in 1784, forbidding the construction of cupolas and steeples in churches [16].

A very extensive proportion of the damage experienced in the events of Lisbon (1755) and Reggio Calabria (1783) was the consequence of the fires that developed after the earthquake in adjacent houses.

The regulation applied for the reconstruction of London after the Great Fire of 1666 [24] was known by the Portuguese civil engineers responsible for the reconstruction of Lisbon. To prevent fire from spreading from house to house the civil engineer Manuel da Maya (1756) proposed that each wall dividing the properties within an urban block should be built above the level of the roof [24] as presented in the drawings of Eugénio dos Santos. A similar rule was introduced in Istanbul in the reconstruction of the Fener-Balat area damage by earthquake and following fire in 1894 [25].

The enthusiasm and admiration for classical architecture developed in the post medieval period and the Renaissance, fostered among others by Alberti's treatises, led to the perception of stone masonry construction, as the most durable and robust form of architecture, the only worthy material for formal and celebrative Architecture, royal and nobles palaces and religious buildings, while brickwork and timberwork was relegated to ordinary construction. However, from its inception earthquake engineering identified as essential attributes of earthquake