Vernacular Architecture

Towards a Sustainable Future

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Local seismic culture and earthquake-resistant devices: Case study of *Casa Baraccata*

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ABSTRACT: In the contexts of high seismic activity, such as the Mediterranean area, many local communities have developed strategies for managing such a risk, adapting all available resources for creating earthquake-resistant rules, shaping not just a particular building culture, but a complex local seismic culture: earthquakes become part of the experience of the community and part of the collective identity of the group, that joins together the efforts to achieve the stability of the building environment. The paper investigates on and analyses the contribution of Mediterranean local building culture in the strategies of defence against earthquakes, through their conditions, logic and specific devices. This paper presents those technical building devices, which are strictly connected to the local seismic culture, and describes in detail the techniques that use timber framed structure, coupled with earthen and stone masonry, to absorb loads horizontally.

1 INTRODUCTION

This paper investigates the contribution of indigenous and vernacular cultures in the strategies of defence against earthquakes, through their conditions, logic and specific devices. The starting point is the fact that many of the current findings on the reinforcement of masonry and earthen buildings have interesting and ingenious precedents in the traditional techniques of the cultures in the Mediterranean, Balkans, Middle and Far fast. While maintaining a poor local language and tacit building rules, many of these architectures have developed the ability to adapt to the surrounding environment and live with the inherent risk of earthquakes. The necessity to rediscover the rules-of-the-art and the techniques used in historical buildings have been acknowledged in the recent scientific debate and a deeper understanding of the peculiarities of such artefacts is considered of fundamental importance for the research of compatible and effective procedures, for the seismic retrofitting of historical buildings.

2 BACKGROUND AND RESEARCH METHOD

In regions affected by frequent and high intensity earthquakes, local communities have developed strategies to protect themselves from the risk, such as building systems or specific devices, designed to reduce the vulnerability of their building habitats.

The extraordinary quality of some of the practices and constructive traditional advice, and their relevance over times and during seismic phenomenon, prompt us to investigate these techniques, in order to understand them and codify the tacit rules to regulate local earthquake-resistant systems.

INN-LINK-S (Innovation of Local and Indigenous Knowledge Systems) Research Centre defines its own research on local knowledge systems as strategic element in the process of local sustainable progress, able to improve the lives of people. According to a systemic approach, we believe that the knowledge of material factors and immaterial ones have to be integrated to codify the tacit variables of a local building culture, and to transmit this knowledge to the experts, as a resource for restoration and contemporary constructions, as well as to the local communities, that must take an active role in the transformation of their environment. In the study of the local seismic culture in vernacular architecture our mission is to define the instruments of analysis, codify the tacit rules that determine the technical devices that have been developed over centuries of experience by the communities, improve and innovate them, and disseminate this knowledge in order to reduce the vernacular architecture vulnerabilities (Dipasquale et al, 2011).

In this paper we investigate the concept of local seismic cultures and we identify some of the strategies developed in the Mediterranean vernacular architecture to protect buildings against earthquakes. Masonry reinforced with Timber structures is selected as a representative typology for seismic building techniques. The case-study of "casa baraccata", which arose in Calabria (southern Italy) following the 1783 earthquake, will be deeper described and compared to others timber framed structures used to reinforce masonry in seismic Mediterranean areas.

The aim of this contribution is to better understand and enhance the earthquake-resistant contribution of traditional devices in order to identify suitable methods for protecting and reinforcing buildings against earthquakes, geared as closely as possible to the specific features of ancient buildings in the local area.

3 LOCAL SEISMIC CULTURES

In a given society, the existence of a local building culture implies the development of a process of awareness and sedimentation of knowledge on the tacit rules that define the constructive systems. A seismic culture can be described as the entirety of knowledge, both pragmatic and theoretical, that has built up in a community exposed to seismic risks through time (Homan et al., 2001). The local seismic cultures include the earthquake-resistant regulations which have not been formally laid out in written code but which are still visible in the building characteristics, in the choice of the site and in the general layout of the territory (Ferrigni, 2007).

The origins and persistence of a local seismic culture can be determinate both by the scale of intensity and the frequency with which the earthquakes occur, and the economic and social conditions, including resource availability and the cultural traditions (Ferrigni et al, 2005). The ancient builders used all the well-known constructive criteria and devices to build houses able to resist earthquakes; perfecting them with time and experience, and comparing the performance of these systems with respect to the effects caused by earthquakes. In this way a process of technical evolution by experimental testing has been developed, that is based on the direct observation of the real behaviour, following telluric forces.

However, in areas where violent earthquakes have very long return periods (as for example in Italy), local earthquake-resistant devices are implemented in the period following the event, but the seismic culture becomes more and more weak over the years, ending in the the loss of the risk awareness by the community.

Earthquake-resistant vernacular reinforcements are numerous, and in a lot of instances, depend on available materials, local building cultures and the skills of the builders. Recurring defence mechanisms consist of: metal lacing systems, buttresses, large section walls, reinforcing arches, technical solutions with the purpose of maintaining the box-like behaviour.

Amongst the ancient cultures the Cretan (2000–1200 BC) and Mycenaean (in the fourteenth century BC) had developed a great sensitivity towards earthquakes. Archaeological excavations have revealed some of the devices used in the ancient buildings. Amongst the remains there exists masonry composed of limestone and gypsum stones, where some of stone elements are placed systematically in the direction perpendicular to the wall. The walls intersect each other tightly and, always crossing at right angles, form dense rectangular mesh networks. This planimetric configuration allows the creation of patterns capable of withstanding strict regimes of dynamic stress. In addition, the work of archaeologists have unveiled inside the large stone blocks, the housings of large pins crossing the rocks to accommodate wooden connecting elements, with the purpose to keep the various blocks connected and to give a strong plasticity to the whole structure.

In ancient Roman building traditions, rows of bricks were set down horizontally through the conglomerate wall section, functioning not only to connect and reinforce, but at the same time serving to interrupt the possible spreading of cracks. This technique is still visible in many walls of the Italian historic cities.

In seismic regions where stone, earth or bricks masonry is the prevalent building technique, the most frequent prevention and/or reinforcement measures consist of adopting the mechanism of mutual contrast between (or part of) the buildings to counteract horizontal forces. (Pierotti et al, 2001).

Some traditional devices used to counteract horizontal forces are: spurs, buttress, wall braces, stairways, loggias, open gallery, and contrast arches which are often located at floor beams level (fig. 1).

Other preventive measures in the history of local building cultures relate to the implementation of design criteria for settlements. An Italian example can be seen in the cities located in the South-East of Sicily, rebuilt after the 1693 earthquake. This catastrophic event completely destroyed sixty cities, leaving others badly damaged.

Reconstruction began almost immediately after the earthquake: the new urban plans are based on linear and reticular patterns, very different from the previous organic medieval schemes; streets are larger with ample spaces, such as squares, designed in order to create outdoor safe zones in case of earthquake. The new buildings present as a rule a stone load bearing walls separated by 4 to 6 m, and two floors. The ground floor is generally used as a storehouse, stable or service room. It is covered by a vaulted structure made of squared stones and mortar (contributing to lowering the gravitational centre of the building) while the intermediate one present a lighter wooden framed floor.

Figure 1. Traditional devices used to counteract horizontal forces in Lunigiana, Italy (L. Dipasquale).

Another prime example of urban anti-seismic reconstruction design is the "Baixa Pombalina", the historical downtown of Lisbon, rebuilt after the disastrous 1755 earthquake into sixty blocks, mostly rectangular, consisting of seven buildings each. The buildings of each block are constructed side by side, sharing the same gable walls (called *gaiola*). The rectangular blocks were designed to form an orthogonal grid of streets; the width of the main streets was approximately equal to the height of the façade, being constant for all the buildings.

4 TIMBER FRAME AS EARTHQUAKE RESISTANT REINFORCEMENT

In areas where earthquakes are endemic, a recurring strategy is the use of wooden elements as devices to improve the earthquake-resistant performance of the building, and also to increase the structural behaviour of the stone, adobe or bricks masonries.

The great elastic properties of wood, its characteristics of flexibility, lightness and deformability without reaching the breaking point, offers good resistance capacity against horizontal loads, and enables the dissipation of substantial amounts of energy. Moreover, timber elements divide the structure into sections, which prevent the spread of cracks occurring in portions of the masonry.

There are many past examples that show how traditional wooden structures have demonstrated good performance during seismic events. By creating horizontal and vertical connections, wooden devices applied to structures with good compression behaviour (such as stone, adobe or brick masonry) can improve the resistance to shearing, bending and torsion forces. There can be various uses of wood as earthquake-proof reinforcement

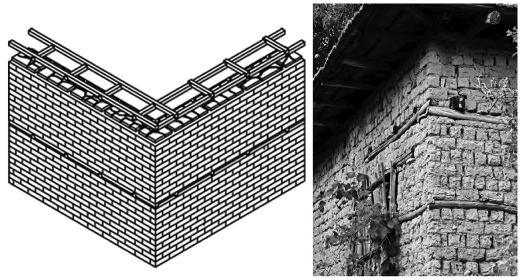

Figure 2. Timber hooping. The building system scheme; example of a building in Antartiko, Greece. Drawing: D. Omar Sidik. Photo: S. Mecca.

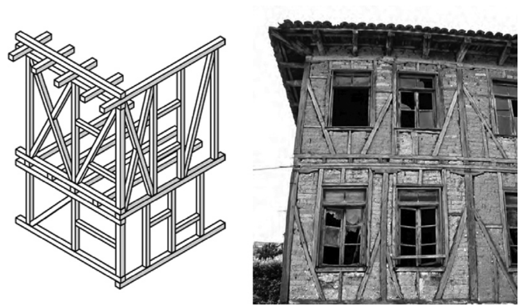

Figure 3. Timber frame System. The building system scheme; example of a building in Kastaneri, Greece. Drawing: D. Omar Sidik. Photo: S. Mecca.

material, but two main categories can be found: the hooping and the frame systems (Figs. 2–3). The first (Fig. 2) provides the arrangement of the circular or square section wooden beams, horizontally disposed within the load-bearing masonry during the construction phase. In many cases two beams are used, one to the inner side of the wall and the other to the outer, connected by transverse wooden pieces. The empty spaces between the beams are filled with fragments of brick or stone. Interlocking systems of nailing's are used for the connections between perpendicular elements. The ring beams can be inserted at the height of the floors, in correspondence to the openings and lintels or regularly distributed along the height of the construction.

The wooden frame system (Fig. 3) is instead articulated in round or square section beams and pillars, and frequently, diagonal bracing elements. The empty spaces defined by the frame are filled with locally available materials (earth, stone or brick).

If the beams are not as long as the entire wall, timbers are connected together through elaborate interlocking systems. In some cases the longitudinal beams are held together in the thickness of the wall by transverse elements that are wedged or nailed, and the corners present additional reinforcement.

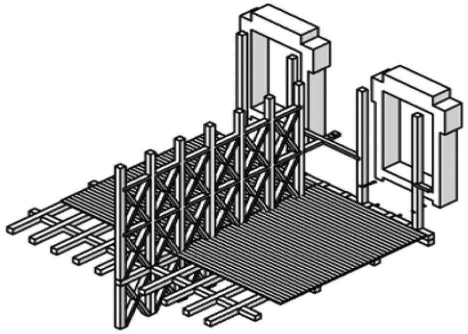

Figure 4. Gaiola building system. Credits: D. Omar Sidik.

One of the most ancient examples in Italy of timber-frame buildings techniques is the *opus craticium* by Vitruvius, today visible in some of the surviving houses of the archaeological sites of Herculaneum and Pompei. The *opus craticium*, was largely diffused in the Roman Provinces, and later developed in different ways in a large number of Mediterranean and European areas.

Relevant examples of timber frame structures together with masonry can be found in Turkey, in Greece and parts of Eastern Europe. In these countries common traditional buildings techniques are based on the use of masonry laced bearing wall constructions on the ground floor level, and lighter infill-frames for the upper stories. The ground floor masonry walls are often laced with horizontal timbers; these elements can be thin timber boards laid into the wall placed so that they overlap at the corners or squared wooden beams.

A very significant example of the use of timber framed structures for masonry anti-seismic rein forcement is the so-called "gaiola" system, diffused in Lisbon after the earthquake of 1755. The technique of Gaiola includes the use of the "Pombalino" wall. This system consists of a set of timber members, embedded along the inner face of the main stone masonry façade wall. The timber elements are made of oak or holm oak squared beams, with a section of 9–12 cm^2. The wooden elements of the structure are framed forming a pair of crossing braces, called in Italy *St. Andrews Cross* and are connected with both the walls and the floors timber beams, forming a cage (*gaiola*) (Ruggeri et al, 1998, Gulkan, 2004, Paula et al, 2006).

The frame is filled with brick, whole and broken pieces, and stone rubble. The interior walls are covered with plaster, hiding the infill and the timber frame. The building is no more than four storeys high, with masonry arcades at the ground floor level, external structural masonry walls (*gaiolas*), internal timber-masonry walls (*frontais*), and internal partition walls (*tabiques*) (Fig. 4). All these structural elements combined have very good earthquake resistant performances, as many experimental studies have shown.

5 THE CASE STUDY OF THE "CASA BARACCATA"

The observation of buildings damage and the recognition of the validity of the traditional techniques led the rebuilding process after the earthquake of Calabria in 1783.

The earthquake that struck Calabria region in 1783 marked an important milestone in the history of the local building culture. The intensity of the shocks and the rapid sequence of the aftershocks (between 5 February and 28 March there have been 5 earthquakes and more than one thousand shocks) caused inestimable damages and more than 50.000 dead. The high vulnerability of the built heritage, combined with the poor construction quality, led to the collapse of most of the buildings in Calabria, located in more than 180 towns, wholly destroyed. After the disaster, the Bourbon government sent out a research team from the Neapolitan Academy of Science and Letters in order to improve the knowledge and the structural aspects of the local constructions. A year after the seismic events a remarkable work, "*Istoria de' fenomeni del tremoto avvenuto nelle Calabrie e nel Valdemone nell'anno 1783*" (Account of the Effects of the Earthquake in Calabria in 1783) was published by Giovanni Vivenzio. It represents one of the earliest concerted responses to earthquake danger, one that was lauded by early 20th-century engineers as a practical means of providing safe construction in earthquake countries. The document drew the guidelines to ensure security and stability to the structures in case of earthquake. Observing the survived buildings behaviour it was detected that the structures with wooden connections proved a greater resistance. Therefore the building directives for the construction of new earthquake resistant buildings suggested the employment of an improved building system, inspired from the vernacular technique of *casa baraccata* (masonry buildings whit a simple timber frame structure), including at the same time some principles of the 1755standard of Lisbon *gaiola* system.

5.1 *The "casa baraccata" building system*

The structural system of the "casa baraccata", composed of a wooden structure in-filled with cob, adobe and/or stones, was present in central and southern Italy from the fourteenth century. The wooden elastic properties were widely known, however, the timber was used without any particular attention to the join between beams.

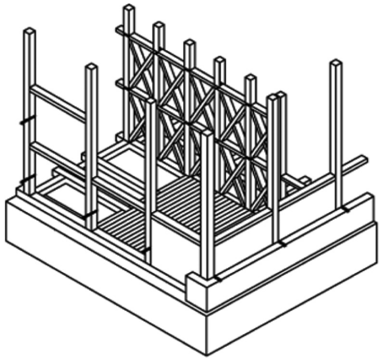

Figure 5. *Casa baraccata* building system. Credits: D. Omar Sidik.

The term “casa baraccata” originally identified the traditional temporary shack (*baracca* in Italian) built as shelter immediately after the earthquakes. Historical documents testify the wide usage, and good behaviour of the traditional *casa baraccata*, diffused in the seventeenth century (Ruggeri, 1988).

The building system designed by Giovanni Vivenzio after the earthquake of 1783 presents a more rigorous architectural scheme where specific devices act to create solid connections and develop a good box-like action between all the elements of the building (Fig. 6). Earthquake resistant buildings should present one or two floors, with a regular and symmetrical plan. The system should consist of timber frame structures with infill stone or adobe (locally called *vriesti*, *bresti* or *mattunazzu*) masonry. The frame elements are covered externally with mortar, thus they are protected from deterioration caused by atmospheric agents and by insects. The external walled structure is made of straight vertical and horizontal pieces, with a square section of 10–12 cm. The internal load bearing walls include sloping timbers as braces giving extra support between horizontal or vertical members of the timber frame. The connections between the wooden beams and pillars should take the form of snaps and rivets (Fig. 5) (Tobriner, 1997). The foundations are made of stone and the cover is a tile pitched roof. The interior walls are often composed of a mesh of interwoven canes and/or branches covered by an earthen plaster, called “incannicciato.

5.2 *Structural behaviour of the “casa baraccata”*

The casa baraccata can be defined as a “dual” construction system, in which the outer walls and the inner wooden frame cooperate to provide a resistant behavior both to vertical loads and horizontal forces. The inner frame is activated during seismic events and provides flexibility to the overall sys-

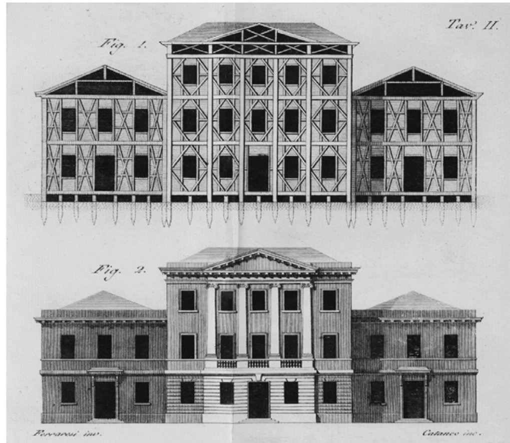

Figure 6. *Casa baraccata.* Giovanni Vivenzio drawings.

tem. The members of the wooden structure are connected to each other and to the external walls through elements of carpentry and/or metal joints, to create a more homogeneous and continuous structural system. The partition walls, in which the wooden beams are placed to form a St. Andrews Cross, act as stiffening members and provide a further contribution to the resistance against lateral forces (Omar Sidik, 2013).

5.3 *Present and future implementation of “casa baraccata” system*

The good earthquake resistant performance of this system was tested during the earthquakes that struck Calabria in 1905 and 1908, registering a magnitude of 7: the buildings suffered few significant damages and limited portions of masonry collapsed; the majority of collapses were caused by the loss of effectiveness of the connections made by nailing.

In the following decades the “Casa baraccata” system has not been implemented with the rigor and the respect viewed in the extensive literature. Many “casa baraccata” buildings present insecure timber connections; vertical, horizontal and sloping timbers inside the masonry are arranged without logic and rigor. The bad quality of the building system processes applied, in addition to the degradation due to time, cannot ensure the survival of these buildings in the case of earthquake.

In 2013, a research conducted by the Italian National Research Council (CNR-Ivalsa) of San Michele (TN) and the Department of Earth Sciences, University of Calabria (UNICAL), scientifically demonstrated the validity of this building system. They reproduced a 1:1 scale portion of a wall of the bishop house of Mileto (Calabria), consisting of masonry reinforced with timber frame, and tested it in a vibrating table, employing a gradually increasing series of alternating movements in both directions.

The seismic performance of the walls proved to be excellent, with a few minor expulsion of masonry, while the timber frames remained almost completely intact. The test confirms the hypothesis that this ancient technique may be favorable applied to modern earthquake resistant buildings, adapting it to the contemporary needs and normative standards. For example, adopting standardized and certified materials, improving joints systems to guarantee a firm connection between the timber elements, adopting adequate connection systems between the timber structure and the masonry, and adopting industrialized production methods.

6 CONCLUSIONS

Building knowledge and know how learned and tested over the years in seismic areas have for centuries formed the unwritten earthquakes resistant building codes; these were codified in recommendation and regulation only since the eighteenth century.

In the case of the aftermath of the earthquake of Calabria, practical knowledge arising from vernacular architecture was used to define the earthquake resistant criteria and to support the reconstruction process. The traditional system of "casa baraccata" has emerged as a relevant seismic resistant building technology, which incorporates innovative methods designed to resist seismic forces. Unfortunately, many of the local seismic resistant techniques adopted, including those in Calabria after 1783, were progressively kept out from the building practices.

One of the missions of the scientific community is to raise awareness that designing buildings with appropriate construction principles and settlement patterns can reduce seismic risk. Over the last decades the culture of reinforced concrete, supported by technical standards and ignoring the traditional materials, has been dominant. However, the improper use of standardized building materials and the hybridization between old and new structural concepts, ignoring the pre-existing structural equilibrium, are not suited for earthquake resistant retrofitting, and can even introduce deep and dangerous alteration to the building. Vernacular architecture requires, therefore, intervention in full respect of the original structural concept, presenting low intrusiveness and, whenever possible, reversibility.

Reducing the vulnerability of ancient buildings, as well as modern buildings, through the lessons of local seismic culture can achieve an appropriate and innovative response to emergencies. Using these lessons from the past, we can even learn something that could help address the severe problems that modern reinforced concrete buildings have manifested after earth-quakes (in Italy for example after the last earthquakes: 2009 in Abruzzo, 2012 in Emilia Romagna).

The awareness of the extraordinary quality of many traditional solutions, and the interest in the preservation of this heritage and the building culture, represents essential achievements through which we can compose models for appropriate effective rehabilitations, future sustainable architectures and settlements. The recognition of local seismic cultures requires a systematic and homogeneous form of cataloguing and archive work, that can used to improve building codes, and to create protocols listing, which can aid technicians to identify suitable methods for protecting and reinforcing buildings against earthquakes, geared as closely as possible to the specific features of ancient buildings in the local area, respecting the original structural concept and, therefore, their authenticity.

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