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VERNACULAR HERITAGE: CULTURE, PEOPLE AND SUSTAINABILITY

Eds. C. Mileto, F. Vegas, V. Cristini, L. García-Soriano

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An architectural catalogue for the study of traditional building features from their seismic behaviour in the 2016 Central Italy earthquake

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Abstract

The preservation of vernacular architecture is grounded on the study of those building techniques adopted in the past, when know-how and craftmanship (the rule-of-thumb for a well-arranged building) governed the spontaneous construction. The advent of new industrial materials and the progressive impoverishment of constructive skills caused the loss of traditional architectural features in favour of a standardized construction. In the framework of the actual debate about the reconstruction of earthquake damaged historical centres, traditional building techniques and materials may play an effective role, as an alternative to a purely aesthetic appreciation, in the conservation of vernacular architecture. This contribution deals with the features of vernacular architecture in the area hit by the 2016 Central Italy earthquake, taking advantage of systematic observations of the built heritage in its context. The appearance of a building was subdivided in 'volume', 'surface' and 'components & materials', and, per each theme, those architectural features which played a role in the seismic performance of a building were collected. This led to the proposal of a catalogue which relates geometric and morphological features to structural ones, as a function of the local construction traditions and the architectural appearance of the townscape. Structural interventions applied over time were also recognized, categorizing them in 'spontaneous', 'standardized' and 'designed'. As in vernacular buildings architectural choices reflect on the structural behaviour, this catalogue and other similar ones are essential for actions (interventions or reconstruction) which are respectful of the built heritage and its values.

Keywords: *catalogue; 2016 Central Italy earthquake; seismic vulnerability; interventions.*

1. Introduction

In absence of archival documents which testify its genesis, the cataloguing of vernacular architecture from actual buildings is a viable option for its knowledge. In Italy, a systematic approach to the study of vernacular architecture dates to the 1970s. Among others, Caniggia and Maffei (1978) focused on the layout of a building in plan (position and number of rooms, position of the staircase) and in the façade (position of openings, number of floors): those recurring patterns among buildings were called 'types'. Later, building materials and construction techniques used in a specific place were collected in 'restoration manuals' (Bertoldi, 1989; Giovanetti et al., 2000; Ranellucci et al., 2004, 2009). These works aimed at both documenting and promoting traditional techniques, conformed to the state-of-the-art rules, as a reaction to standardized building practice that appeared in the 1970s, whose application had been widespread in the reconstruction or strengthening of buildings hit by the earthquakes in those years (1976, 1979, 1980) (Sbrogiò et al., 2022). Giuffrè (1993) and Carocci (1999), firstly analysed the capacity of vernacular architecture when seismic actions are involved. They proposed a relation between building features – resulting from the specific layout of a type, thr rules-of-thumb (i.e., *typical vulnerability*, (Doglioni, 2005), and the transformations that happened over time (i.e., *specific vulnerability*) – and seismic damage mechanisms, which were distinguished in first and second mode. A first mode failure (out-of-plane mechanisms) consists in the movement (translation or rotation) of a bearing wall of a building outwards its middle plane, whereas in a second mode failure (in-plane mechanisms), these movements are restrained to the middle plane of a wall.

The latest earthquakes in Italy (2009, 2012, 2016) stimulated anew studies on the architectural and construction features and the seismic response of buildings in villages and small towns, where the built heritage is mainly composed by vernacular architecture. For instance, Carocci (2012), Centauro et al. (2014), Taffarel et al. (2015), Brunori and Zampilli (2021) concluded, in spite of their different experiences, on the importance of a careful evaluation of traditional buildings techniques and architectural features, seeking for a viable reconstruction process, also with the support of compatible strengthening techniques. In addition, the documentation of the built environment can now rely on tools which allow precision and wide range at the same time, e.g., laser scanners and drones (Croce et al., 2019), and which relate information to geometry, in a holistic design approach (Savini et al., 2021).

The owners of vernacular buildings appreciate functionality and usability over material and technical authenticity (Strati, 2017). Furthermore, limited resources favour those interventions which are more effective in terms of costs and structural safety, if compared to more refined solutions, suitable to cultural heritage buildings (Pianigiani et al., 2020). Interventions on vernacular architecture can easily alter values linked to material culture, which may be sacrificed to aesthetic ones. However, a ban on interventions would condemn such buildings to abandonment, owing to poor usability and safety conditions, and, ultimately, to their loss (Giuffrida et al., 2020; Oteri, 2019).

The building activity in a territory selects those architectural and structural features which are the most adapted to environmental conditions (Giuffrè, 1993). Earthquake is a rare event and, therefore, specific provisions against it (the 'local seismic culture' cf. Ferrigni, 2015; Scibilia, 2017) belong to repairs rather than original construction, e.g., buttresses, tie rods and wall-base enlargements. The level of conformity of a building to both the supposed 'optimal' situation and a good overall state, as a function of maintenance and transformation, is a possible description of vulnerability and it results in specific damage patterns (Binda et al., 2007; Valluzzi, 2016).

In the study of vulnerability factors, two approaches are possible. A 'normative' one, which extracts from buildings individual critical situations matching to these compatible damage patterns (Binda et al., 2007; Doglioni, 2005). However, in those buildings where these factors can be recognized, it is hard to predict the actual damage. A 'descriptive' one (Giuffrè, 1993), in which vulnerability factors appear as features of building types, determining their structural behavior (i.e., damage mechanism). The association between vulnerability and damage patterns, as well as between building types and a certain town, is very specific and it may prevent a generalization.

Based on the idea that the features determined by the building 'dialect' of a certain area also define the (empirically determined) 'good' structural behavior of a building, it is possible to identify the best and worst situations and to use them for cataloguing purposes.

The paper proposes an intermediate approach, in which vernacular architectural features are collected in types, according to both their overall appearance and their influence on the structural behavior of a building. Structural transformation processes were also accounted for.

Therefore, these types can be generalized to a larger area than a single town or village, like a district or a territory which is rather homogeneous according to geographic and historic conditions. This is the case of the area hit by the 2016 Central Italy seismic sequence, which spanned between August 2016 and January 2017.

2. Methodological approach

Facing the damage patterns induced by the 2016 Central Italy earthquake (§3), the Authors wondered which factors concerning the *appearance* of the architectural layout of a historical centre (*townscape*), i.e., masses, lights and shadows, textures, influenced the structural response of its masonry buildings to seismic loads.

To that end, the proposal of a catalogue which collects the visible architectural hallmarks started from a literature review of those well-known factors which (typically) impair the seismic performance of the built heritage; they were also compared to real damage patterns (§4). For systematic purposes, the analysis of townscapes was split into three themes: i) *volume* and ii) *surface*, as determined by functional, social, and economic needs; iii) *components & materials,* as a function of the climate, building tradition, and availability in the surroundings of the building site. These elements of buildings are shaped by their inhabitants according to specific social, historic, economic, and geographical background. Architectural and non-structural details (e.g., lintels, chimneys, cornices, mouldings, etc.) were not considered, as a large-scale observation was carried out.

These choices aimed at reducing the influence of those details which distinguish each centre, despite the same geographical area, and at extending the validity of the final catalogue (§5) also to other vernacular centres.

The methodological approach is therefore independent from both the architectural layouts and the building materials. In addition, it could help in interpreting the damage of past earthquakes, provided that enough information on building features and damage was available, e.g., by the means of detailed survey campaigns and photographs.

3. Study area

The research focused on masonry buildings in 25 historic centres in Marche and Umbria regions in Central Italy, spread over the districts of Perugia, Macerata, Fermo and Ascoli Piceno, the most heavily hit by the earthquakes in 2016. These areas are characterized by a hilly landscape progressively changing into the harsher Apennine environment. In most cases, towns and villages were built in the Middle Ages as castles or fortresses in strategic positions, close to crossroads, important churches, bridges, or fords. As the circulation of people and goods was limited, building materials, such as stones and mortar, are those available in the surroundings of the settlement (Valluzzi et al., 2021). Those historical centers resulted from a spontaneous process of aggregation of masonry buildings, clustering around churches and castles or stretching along roads (Caniggia & Maffei, 1978).

4. Reconnaissance of architectural features with a structural role on built heritage

According to Giuffrè (1993) and Doglioni (2005), the vulnerability factors of vernacular masonry buildings can be categorized in the following items: i) position in town-blocks; ii) misarrangement in architectural layout; iii) poor structural details; iv) transformations which reduce the load-bearing capacity of walls; v) poor connections among walls and among walls and floors; vi) structural interventions with modern and incompatible materials such as reinforced concrete (r.c.). The maintenance state, which may influence the seismic performance of a building as well, was not considered in this work.

4.1 Volume

The position of a building within a block determines the mutual buttressing effect: corner and end units showed higher damage than internal ones as they lack of it (Fig. 1, left). The façades of clogging units, i.e., those built between already existing buildings, were often not properly connected to the adjacent ones. Misaligned cells in plan are exposed to corner overturning as well (Fig. 1, right). These situations, strictly connected to construction processes, favored the first mode mechanisms (overturning of walls and corners) (Fig. 2).

Fig. 1. Terrace in Castelsantangelo sul Nera: damage on head unit (left), overturning of façade in jutting unit (right)

Fig. 2. Overturning of façade in a clogging unit (Nocria)

As regard the elevation, some units stand higher than the eave line of the surrounding ones and, therefore, have free walls on one or both sides. As these latter were generally unrestrained by tie rods, they suffered of out-of-plane mechanisms, causing damage also to the roof of the adjacent units (Fig. 3). A unit higher on both sides than the neighboring ones was the most unfavourable situation.

4.2 Surface

Vulnerability is related to the geometric layout of a façade, which in turn is determined by the internal usage of a building. The structural behaviour of a façade may result from either a low conception of the architectural layout or modification processes which reduced the load-bearing capacity of the structural elements. Windows express the arrangement of rooms inside and delimit the loadbearing pier elements, which should stretch from the ground to the top level of a building. Overall, openings can be either regularly spaced or clustered; referring to horizontal distribution, the two key parameters are their mutual distance and the distance from the edges of a façade. Additionally, considering their vertical distribution, openings can be either aligned or shifted between storeys. Clustered windows determined a lumped distribution of stiffness and masses, which triggered out-of-plane mechanisms. Tightly spaced windows reflected in slender piers, which rapidly reached their peak strength (in-plane damage), whereas slender piers at corners easily overturned during the quakes. Shifted windows or shop windows and garage doors at the ground floor interrupt piers at an intermediate storey. In this case, the lack of a proper support caused the collapse of piers. Considering the interaction of adjacent units, openings can be staggered between the two buildings, because of different storey height. This caused pounding, i.e., cracks at the vertical joint between the two buildings, or in-plane damage (Fig. 5 left). Adjacent buildings with different floor stiffness (e.g., a timber floor and a r.c. one) or façades with a relevant difference in number and distribution of openings were exposed to similar situations.

Fig. 3. Overturning of standing walls (Castelsantangelo sul Nera)

In the study area these factors were often combined, resulting in severe damage patterns (Fig.

4). Conversely, provided that masonry quality is good, a well-arranged façade system, i.e., squat piers and an even distribution of openings ensured an overall behaviour with minor damage.

Fig. 4. Crumbling of masonry and shear damage owing to misaligned openings (Visso, courtesy of Eng. Falsetti)

4.3 Components and materials

Façades are made of undressed or roughly cut stones, randomly laid in poor mortar (lime and/or clay); their cross-section is divided in two or three leaves, without bonding stones. Overall, the poor masonry quality (Borri et al., 2020) eased both the crumbling of walls, owing to the lack of connections in the cross-section, and first-mode mechanisms, owing to poor interlocking between walls. Crumbling took place before any damage mechanism could activate, and it interested the outward layer of a wall, especially when r.c. roofs and tie beams were added to the building. Damage associated to crumbling is severe and often determines the loss of a building (Fig. 4).

Traditional horizontal structures are made of hardwood timber joists resting in sockets in walls. Loadbearing masonry vaults were sometimes observed at ground floors, but their usage was not widespread.

Starting from the 1970s, many buildings underwent interventions, as repairs and strengthening, with standardized methods and r.c. elements, according to the seismic codes passed after the earthquakes in the late 20th century (Sbrogiò et al., 2022; Sisti et al., 2022). Three categories of interventions were defined, as:

i) ‘Spontaneous’ interventions, i.e., devices which were applied in the past based on the local seismic culture, i.e., the empirical experience of contrasting the overturning of walls. These were buttresses at the foot of walls, buttressing arches between adjacent but separated buildings and metal tie rods. They contrasted first mode mechanisms and led to visible in-plane damage.

ii) ‘Standardized’ interventions, which were applied starting from the 1970s, in compliance with seismic codes and handbooks, prescribing rigid floors (Sbrogiò et al., 2022). Standardized r.c. elements replaced existing floor joists and roof beams, and r.c tie beams were added to connect the walls at floor and roof levels. These interventions, which added mass and stiffness to the horizontal structures, were not compulsorily associated with the strengthening of the bearing walls, which crumbled, resulting in severe damage (Fig. 5 right). The available strengthening solution for masonry walls was a cement plaster reinforced with a steel mesh.

Fig. 5. Left: pounding owing to staggered roofs (Pieve Torina); right: masonry crumbling and r.c. roof collapse (Campi Alto)

iii) ‘Designed’ interventions, i.e., the most suitable strengthening action for a specific building according to models and simulations. They target masonry through injections and fibre reinforced plasters, floors with a light stiffening, connections among parts (Senaldi et al., 2014), by the means of tie rods, steel bars, composite materials, in place of r.c. elements.

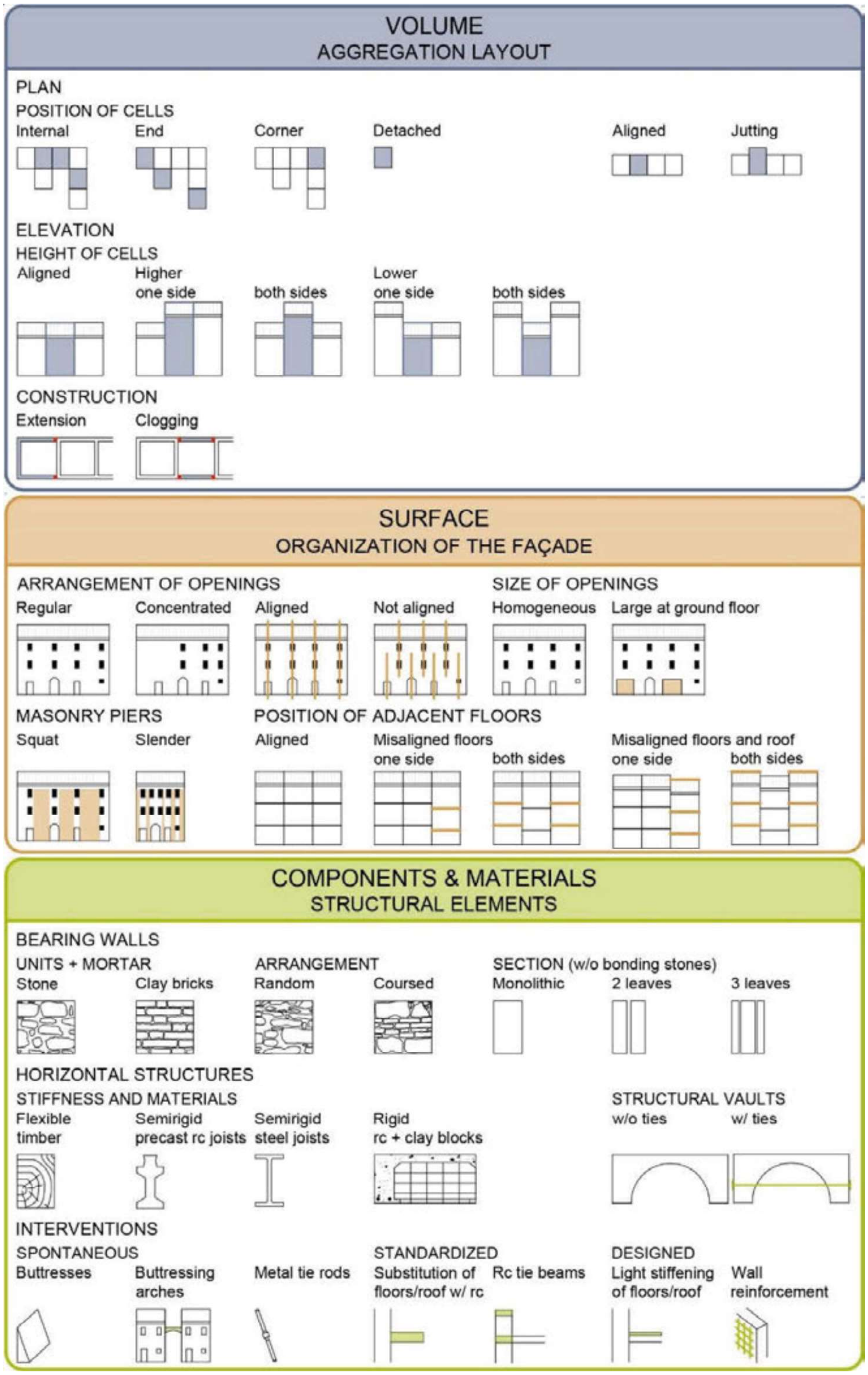

Fig. 6. Proposal of a catalogue of architectural hallmarks in a historical center

These interventions are more respectful of material and architectural features as they search for both material compatibility (weight, stiffness) and the collaboration with original parts. However, they are a viable option only in cultural heritage rather than vernacular buildings. Also in this case, an insufficient strengthening of the walls led to masonry crumbling, although localized if compared to that determined by standardized interventions.

5. Discussion

Fig. 6 shows the resulting catalogue for the ordinary masonry buildings in the study area, grouped as described in § 4.

The observations highlighted that damage patterns resulted from the interaction of multiple factors. The overall structural response of a building was mainly due to its components and materials, i.e., to the masonry quality. Secondly, it was governed by the surfaces, i.e., the layout of façades as a function of the distribution of stiffness and masses, which determined the damage distribution. Finally, the irregularity of the built volume determined localized damage with cracks at the interfaces between buildings and damages due to the fall of debris from adjacent units.

Proper interventions (type ii or iii) on masonry walls obtained minimum damage to buildings, even in the epicentral area (Sisti et al., 2022). However, the strengthening of walls determined a relevant alteration of the original features of a building.

6. Conclusions

The systematic observation of both the features of and the seismic damage to masonry buildings in the area of the Central Italy 2016 earthquake led to the proposal of a catalogue of vernacular architecture. A building was decomposed in *volume*, *surface*, and *components & materials*, i.e., those architectural features related to townscapes which also played an important role in the seismic behavior. Structural interventions on buildings were widespread in the study area and they were therefore included in the catalogue. The observations confirmed the role played by some well-known vulnerability factors (e.g., position of buildings in town blocks, dimension of the piers in a façade) or excluded some others (e.g., number of floors). Masonry quality and interventions were crucial in the determining the final behavior of a building. Poor masonry determined the local crumbling of walls, which was eased by the mass and stiffness of floors and roofs replaced with r.c. elements in intervened buildings.

Material impoverishment, economic downturns, depopulation, and seismic vulnerability put the values of vernacular architecture at risk. However, safety is a requirement for the conservation of vernacular architecture. Any design proposal must start from the improvement of masonry quality, which experience proved to be crucial for safety. Other interventions can rely on the inventory of traditional techniques and the composition of building materials as described by restoration manuals. A specific awareness on this theme by practitioners and supervisors is the only hope for both a viable reconstruction of that which has been damaged and future effective strengthening campaigns.

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