Conservare il patrimonio tangibile. Strategie per il consolidamento, la cantierizzazione, e la riduzione del rischio sismico degli aggregati urbani dell'Appennino italiano: il borgo di Castel d'Alfero (FC)

Preserving tangible heritage. Strategies for the consolidation, the construction site, and the reduction of the seismic risk of the urban aggregates of the Italian Apennines: the village of Castel d'Alfero (FC)

Abstract:

L'articolo propone un'iniziale riflessione sulla struttura insediativa dell'aggregato urbano di Castel d'Alfero (FC), la cui vicenda si colloca nella fase di popolamento successiva al crollo dell'Impero Romano ed all'introduzione, nell'alta valle del Savio, del potere feudale. L'analisi verte sul sistema ambientale e architettonico e sulle dinamiche che hanno condotto all'*insediamento* prima, le cui ragioni risiedono nella strutturazione di specifici sistemi produttivi e di percorrenza, e all'*abbandono* poi, indotto tanto da caratteristiche ambientali quanto da condizioni socio-culturali che, nondimeno, hanno favorito un modello di sviluppo di tipo urbano. Date tali premesse vengono così condotte attente considerazione sulle problematiche legate alle modalità e alle strategie di messa in sicurezza, al consolidamento e, aspetto non meno importante, alla tematica della cantierizzazione, che assume, ora più che mai, un ruolo decisivo per la riuscita di un corretto progetto di conservazione in ambiti "*tecnicamente avversi*". La fragilità di questi contesti, non solo in relazione agli elevati ma anche alle percorrenze storiche che costituiscono elementi identitari di grande valore storico testimoniale, impone grande attenzione all'organizzazione del cantiere, alla mobilitazione dei mezzi d'opera, allo stoccaggio dei componenti e alla costruzione di sistemi di ritegno e sostegno. Alla luce dei recenti e continuativi eventi sismici che hanno colpito il territorio italiano e con esso parte del suo patrimonio tangibile e non tangibile, le strategie di riduzione del rischio sismico richiedono particolare considerazione e pongono nuovi interrogativi su come e cosa fare di fronte alla vulnerabilità di questi manufatti, per loro natura "poveri". L'articolo propone, inoltre, le possibilità applicative delle cosiddette *meta-barriere a sistemi risonanti,* in grado di isolare sismicamente un aggregato edilizio (o un sistema isolato) deviando onde superficiali aventi frequenze che risulterebbero altrimenti particolarmente dannose. Si evidenziano dunque le peculiari proprietà dinamiche dei *meta-materiali* costituenti, analizzando la struttura geometrica e il funzionamento dei componenti risonanti allo scopo di valutare quali tipologie di onde è possibile deviare o deamplificare.

The essay proposes first a reflection on the settlement structure of the urban aggregate of Castel d'Alfero (FC), whose story takes place in the phase of population following the collapse of the Roman Empire and the introduction into the Savio valley of feudal power. The analysis focuses on the environmental and architectural system and on the dynamics that led first to the settlement, whose reasons lie in the structuring of specific production and travel systems, and second the abandonment, induced both by environmental characteristics and socio-cultural conditions, that nevertheless favored a model of urban development. Given these premises, the paper continues with careful considerations of the methods and strategies for securing, consolidating and, most importantly, jobsite activities coordination, which have now, more than ever, decisive role for the success of a proper conservation project in "technically adverse" areas. The fragility of these contexts, not only in relation to the buildings but also to the historical routes that constitute identifying elements of great historical testimonial value, requires great attention to the organization of the site, the mobilization of the means of work, the storage of the components and the building of retention and support systems. Having regard to recent and ongoing seismic events that have affected the Italian territory and, with it, part of its tangible and intangible heritage, reduction of seismic risk strategies requires careful consideration and poses new questions about how to approach the vulnerabilities of these structures, "poor" by their nature. The article also proposes the application possibilities of the so-called meta-barriers with resonant systems, capable of isolating seismically a building aggregate (or an isolated system) deviating surface waves having frequencies that, otherwise, would be particularly harmful. The peculiar dynamic properties of the constituent meta-materials are analyzed of in order to evaluate how the locally resonant structures can manipulate the superficial seismic waves.

Premise.

The Italian territory is characterized by a considerable number of small settlements that constitute an essential component of our cultural heritage for permanence of typological and morphological structures as well as continuity of constructive traditions and use of autochthonous materials. As has been pointed out several times, this is a largely endangered heritage. General depopulation phenomenon due to the twentieth century migratory movements produced visible effects of abandonment of many inhabited areas and territories in the three decades following the Second World War. These effects have naturally been more evident in areas with a marked rural economy, especially if poor, as consequence of prolonged migratory flows, systematic from the countryside towards the city or, alternatively, to areas with more developed agricultural economies. The phenomenon has affected, in particular, mountain areas or internal hills, compared to those of the foothills or coastal areas, characterizing those settlements in orographically penalizing positions because they are linked to routes now disused, or because of their remoteness from the poles of greatest economic attraction and therefore disadvantaged by the emergence of fast mobility and new structures linked to large communication infrastructures.

The strong population wane and the consequent abandonment of small towns has profoundly affected above all the Central-South of Italy and a good part of the Apennines[1]. The "ghost countries", according to an estimate of at least a decade ago, represented about 72% of all Italian municipalities, a value that has increased because of the seismic swarms of 2012 and 2016 that devastated Central Northern Italy significantly, and in many cases irreversibly, accentuating this phenomenon and in many cases reaching the complete abandonment of these realities. However, these issues will not be dealt with here, because of the rich and constantly updated existing literature. Instead, the essay exams the village of Castel d'Alfero, in the municipality of Verghereto, near Sarsina (Emilia Romagna[2]), analyzing the problems related to the material conservation of one of these villages, especially in terms of actual feasibility, while aware of the limits of studying a single case[3].

1. Castel d 'Alfero: an abandoned village in the Romagna Apennines.

The logic of development of the secondary ridge paths and of the high promontory settlements that characterize most of the Apennine range can also be found in that portion of the Romagna territory where Castel d'Alfero was built, presumably in the eleventh century.

The fortified settlement laid out in a north-west, south-east direction on the rocky outcrop overlooking the valley, at the beginning of the thirteenth century, was subject to the Guidi di Modigliana and then passed to the Abbey of Trivio, and finally tying its fortunes to those of the Municipality of Florence. Castel d'Alfero is mentioned in documents such as *castrum et eius curtis*

[1] «*Il fenomeno dei «paesi fantasma» interessa molto il Centro-Sud e le zone appenniniche. I piccoli centri alpini si sono salvati grazie all'industria del turismo, quelli del nord invece hanno continuato a sopravvivere grazie alla vicinanza alle grandi città industrializzate e, fatto non secondario, grazie a infrastrutture tale da consentire agli abitanti di raggiungere le città in poco tempo e in modo piuttosto confortevole. Al Centro-Sud la situazione è invece molto diversa. Migliaia di paesini si sono spopolati. La situazione più pesante si registra in Basilicata, dove ben 97 centri sono a rischio estinzione, nelle parti montuose della Sicilia e della Sardegna, nelle aree interne di Marche e Toscana e su tutto l'arco dell'Appennino Meridionale, dall'Abruzzo alla Calabria, passando per il Molise*», Postiglione 2009, p. 11.

[2] De Luca 2015.

[3] In confirmation of this, it should be remembered that the first level cards elaborated by the National Group for Earthquake Defence (GNDT) of the CNR for the detection of the exposure of the vulnerability of buildings - the first models date back to 1997- as well as the Manual for their compilation, usability and damage in the seismic emergency (AeDES), of 2013 and 2014, - <http://www.protezionecivile.gov.it/resources/cms/documents/2_LRManualeAedes_31_ottobre_2014 GU> subject to numerous application tests have limits in relation to:

- The impossibility of foreseeing all possible types of construction, even though they operate in relatively small areas;
- Difficulties in recognizing building types;
- Variability of the typology within the same building "aesthetically" similar, and therefore classifiable as equal. (Zamboni 2017, 50).

See also D.P.C.M. 9 February 2011. *Assessment and reduction of seismic risk of cultural heritage with reference to the technical standards for buildings as per Ministerial Decree 14/01/2008.* Official Gazette no. 47 of 26/02/2011 – Ordinary Suppl. n. 54; *Guidelines for the survey, analysis and design of repair and seismic consolidation of masonry buildings in aggregate.* Draft October 2010 Reluis.

as it has a fortress at the bottom, an upstream tower, a side entrance with a door, and is defended by a perimeter wall[4].

The village, damaged several times by seismic shocks that have marked this territory over the centuries, today preserves a sixteenth century structure, characterized by subsequent developments that configured it as a rural village and selected a repetitive typological plant functional to rational use of internal space, defined by the sum of elementary cells leaning against each other. The typological structure built along the only path made in the rock, is similar for each component cell: transverse partitions in masonry, double transversal facing, access ladder, loggia, oven, dwelling. On the basis of this model re-proposed with exemplary rigor, a space of common use has been obtained, the internal courtyard, a field of mediation between exterior and interior, the loggia overlooking the courtyard, and a private space for living[5].

Local typology is nothing more than the characterization of a more extensive construction criterion depending on the availability of raw materials and the cultural influences[6]. The structures were constructed with locally sourced material from the Alberello river such as oak wood, sandstones and local sand. The masonry, perhaps once plastered, has external paraments made of hewn ashlars in sub-horizontal rows, wall cores obtained with pieces of sandstone, cantons and moldings of doors and windows with squared blocks. The mortars used are mostly hydraulic lime with inert materials of fluvial origin, loaded with very small pieces coming from the stone milling. The wooden slabs, often with simple warping (beams and planks) are built in oak; the original roof covering, in sandstone slabs. Castel d'Alfero has been readapted for different uses as evidenced by the land registers of 1810 and 1826 and the direct analysis of the buildings of the village. This has modified, in many cases, the arrangement of the plant homogenizing sometimes to the recurring types in the single-family building of the twentieth century and thus altering static structures already precarious[7]. The Castel d'Alfero was abandoned in the second half of the twentieth century due to repeated seismic shocks that marked the territory in 1918, 1919 and the summer of 1962[8] and, changing roads and economy of the surrounding territory. The surrounding village had been entirely abandoned by the early 1970's except for short stay holiday homes; nevertheless, given the quality and consistency of the building, the complex has been bound by the MiBACT with the Decree of 17 January 1996[9].

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[4] Berardi *et al.* 2000, p.109.

[5] Corzani 1988, pp.16-19.

[6] Giuffrè 1993, p.145.

[7] The residential nature of the historical aggregates entails a series of mutations inside the masonry box that can generate potential vulnerabilities to the effects of the earthquake due to building remelting, property distribution and changes in use. (ivi, 97)

[8] Formisano 2013. <https://emidius.mi.ingv.it/CPTI15-DBMI15/query_place/>, 21.05.2018.

[9] The complete card of Castel d'Alfero is the n° 040044_448 of the WebGis of the Cultural Heritage of Emilia Romagna drawn up by the Regional Secretariat of Emilia Romagna of MiBACT. <https://www.patrimonioculturale-er.it/webgis>, 08.05.2018.

Fig. 1.

2. The vulnerability of a "ghost village" of the Romagne.

The need to safeguard a site like this, whose substantial unity can still be read in the stones of which it is composed, requires a reflections: first of all, on the vulnerability of these aggregates; secondly, on possible executive strategies related to the methods and techniques of intervention, with particular regard to the response of the built to dynamic actions[10] and, specifically, to the earthquake[11]. First of all, some aspects that generally characterize a large part of the Apennine settlement structures must be noted: materials available in situ; "poor" execution techniques, exacerbated by lack of maintenance operations, which configure artifacts with sometimes unpredictable behavior, already in static phase; soils with variable behavior; complexity of the construction context[12]. The knowledge of the morphological, hydrological and geological characteristics of the territory therefore assumes a very great importance.

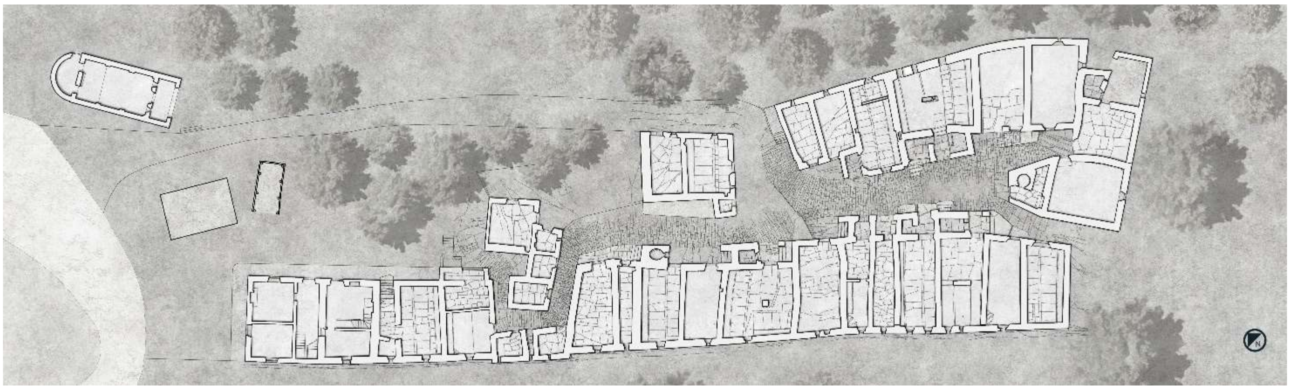

Fig. 2.

Castel d'Alfero was born on a marly-arenaceous outcrop[13], classifiable as a land with elastic behavior and therefore able to promote high frequency vibrations, less harmful for the building

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[10] Chopra 2000.

[11] Binda et al 2005; Carocci et.al. 2007; Carocci, Marino 2009; Carocci et.al. 2014; Giuffrè 1993; Scalora, Monti 2010.

[12] Brogiolo, Cagnana 2012, p.54.

[13] *Piano Strutturale Comunale*, Municipality of Sarsina Historical settlement system - Recovery plan of Castel d'Alfero - Report (Elaborated CS.1A). Implementation of Articles 21 and 28 of the LR. 24 March 2000, "*Disciplina generale sulla tutela e l'uso del territorio*".

structures[14]. The state of preservation that characterizes the components, in spite of a "rule of art"[15] often applied by local builders during the construction of the building, makes us tend towards not reassuring evaluations: you only have to look, for example, at the state of abandonment of the structures and the transformations, performed basically for functional purposes without any attention to the elements of the aggregate. We therefore note: a general absence of continuous and regular bottom planes between the constituent units, especially in the presence of small diachronic superfetations, as well as superficial foundations almost never connected to the more solid layer of the rocky outcrop; the lack of clamping between diachronic walls (and sometimes total disconnection) as well as the absence of an effective connection between floors and vertical structures; pushing roofs even if they tend to be lightweight; offset between adjoining floors due to the steep slope and, lastly, elimination of some floors that undermines the stability of some paraments against compressive and bending mechanisms.

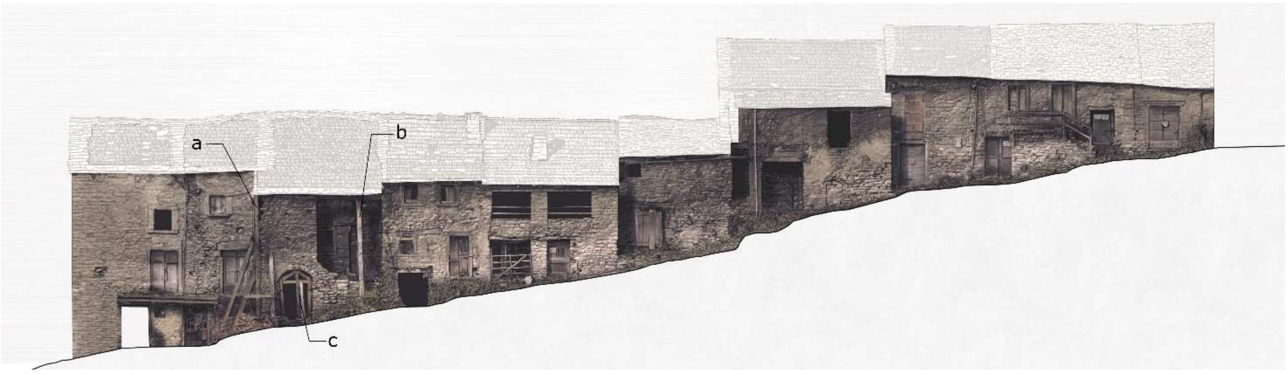

Fig. 3.

Reliefs also amplify the effects of the earthquake: in this regard[16], the reference legislation defines how to evaluate the topographic amplification coefficient based on empirical observations, using, in the absence of local response analysis, a table-based method depending on the selected topographic category. Since the calculation actions assume a much higher magnitude, following the spectral amplification, "complicating" the seismic improvement procedures, it is always advisable a further geotechnical specification as well as surveys to verify the presence, the qualities and the size of the foundations.

3. Which strategies for the protection of the built.

The design choices that often guide the intervention on the historical building not bound by the Italian laws for protection of cultural heritage (it is not, fortunately, the case of Castel d'Alfero), neglect the respect of that intangible heritage made of knowledge, construction techniques and use of local resources, handed down from generation to generation. Simplified and often standardized procedures for calculation and execution[17] are often preferred.

Referring to what has just been said, it is enough to think about what happens in current practice when we proceed to the consolidation of foundations by means of indirect system to reach more consistent substrates. Often, actually, it is not considered that, in fragile contexts such as those in question, these techniques are quite invasive if not even harmful to the survival of the built: both

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[14] A different case is that of those settlements built on incoherent alluvial soils or clayey nature that enhance the surface waves favoring low-frequency oscillations, as they possess inelastic behavior.

[15] Della Torre 1996.

[16] D.L. 17 January 2018," *Norme tecniche per le costruzioni*".

[17] http://www.minambiente.it/pagina/definizione-di-patrimonio-culturale-immateriale. 09.07.2018

for the inevitable vibrations induced by the installation procedures, for the tangible difficulty in intervening inside the buildings (unless the removal of existing floors[18]), and finally for the complexity of handling machinery on distances designed for simple wagons and slopes particularly accentuated, as in the case of Castel d'Alfero.

It is therefore clear that the protection of the built environment, at least at a conceptual level, must be directed towards procedures that, working on the "boundary conditions", do not compromise the material consistency of these objects and acting, so to speak, on the characteristics of the seismic action (spectral characteristics) as already extensively discussed in the specific literature.

The most common techniques to improve the behavior in dynamic phase, so to mitigate the effects of seismic action on the artefacts, can be identified in these procedures: enhancement of mechanical characteristics; conferment of higher states of compression in the masonry, aimed at increasing stability; stiffening of the floors and connection between the parts; distribution of loads according to regularity criteria. Thus, a successful restoration intervention depends, in these cases more than in others, on the ability of the designer to identify proper solutions, skills of workers in the use of traditional techniques, which best suit the needs of conservation, and nature of the places, for the organization and management of the construction site. Let’s start by saying that any intervention on the historical construction cannot disregard the initial security of the building.

[18] Donà, De Maria 2011. Procedure that would require careful storage of temporarily removed components.

Fig. 4

In spite of this, in the aftermath of the earthquakes that have marked Italy since the end of the first decade of this century, the temporary structures of support and restraint often continue to be designed with low attention, sometimes aggravating conditions already prejudiced by earthquakes. It is not at all uncommon that the two mentioned types, radically different in the explicit function, are used in a substantially wrong way: we refer to the use of support structures, leaving out any element aimed at restraint, within extremely vulnerable artefacts towards mechanism outside their axis or geometric plane. This is clearly in a case of safety measure at Castel d'Alfero.

Fig. 5

One of the architectural units, shown in figure 5, already shows advanced kinematics. The facade is completely detached from the orthogonal walls and therefore much more vulnerable to accelerations and pushes out of the plane. Such circumstance, in this case completely neglected, is instead of great importance. It is opportune, in these situations, to predispose retention systems carefully designed even if an analysis of local stability results verified[19]. This is obviously finalized, at least, to allow the visit of site/construction-site in safety so to proceed to further building investigations.

The currently installed aid systems, limited to the terminal unit only, downstream of one of the two aggregates, are clearly identifiable in figure 3. In particular, the following restraint and support systems have been set up at the terminal unit:
- props for the containment of the side parapets in masonry (a);
- prop supporting the wooden lintel (b);
- frame supporting the masonry arch (c).

However, safety interventions carried out are not particularly efficient against actions and loads outside the mechanical plane of the main facade. Nevertheless, the stability of the terminal unit is connected to that of the adjacent one, completely devoid of supports and restraints.

An essential methodological principle is therefore outlined, but it does not seem to be entirely obvious: safety of any building is always the result of a project to be carefully evaluated on a case-by-case basis.

Summarizing in the essential principles what we said, we agree[20] that the preservation of the historical building, regardless the protection of ancient matter, is based primarily on the respect of laying techniques, the protection of individual components, ensuring their proper functioning, as well as on the evaluation and acceptance of signs of transformation of a building, appreciated precisely for their *alterswert*, which is the value of antiquity. For the foregoing, we also believe that among the conservative practices there are also those necessary to ensure a better behavior under the effect of earthquakes. This also means taking charge of the "history" of that artifact, of the phases of which it is composed, of its state of conservation, of the geometries. It is therefore necessary to pay attention, for example, to the tapering of its walls, to the position of the holes, to the misalignment of the floors, to the elevations and so on. Furthermore, it must not be forgotten either that the building, as in the case of Castel d'Alfero, is part of an aggregate and therefore of an articulated system, heterogeneous because often diachronic in plan and in elevation. These characteristics can sometimes increase its vulnerability[21].

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[19] Given the randomness that often characterizes the analytical calculation in the identification of macroelements, then the actual mass and geometry involved in kinematics movements.

[20] Della Torre 1996; Pracchi 2008, Zordan et al. 2009; Scalora, Monti 2010; Blasi 2013.

[21] Binda 2005; Lagomarsino, Ugolini 2005; Borri et al.2007; Carocci, Marino 2009; Zamboni 2017.

Fig. 6

One should take a hint from the approach to the construction of those who in the absence of *technology* masterfully used the *technique*[22] by efficiently combining the materials and pursuing their natural way of behaving under loads of various kinds. In other words, the study of the behavior that naturally characterizes a constructive component can represent an effective aid in the improvement of the structural static and dynamic characteristics. It is plausible to think that ancients tried to create solid constructions, according to the Vitruvian concept, and for this reason also anti-seismic, without distinguishing the two aspects, certain that *firmitas* was enough to deal with earthquakes[23]. The evolutionary process of masonry constructions, from antiquity to the modern age, has been supported by the practical knowledge of master builders and by technological development. For this reason, it is difficult to distinguish for ancient buildings those rules dictated by pure seismic prevention criteria or those that derive from other structural needs. Actually, certain constructive expedients that would seem expressly aimed at optimizing the static behavior prove to be effective against stresses induced by the earthquake[24]. In this regard we could distinguish the so-called anti-seismic criteria, connatural to the construction itself, from the anti-seismic measures, which condition the structural behavior retrospectively.

We could define the following geometric-constructive characteristics as anti-seismic criteria:
- presence of well-packaged wall cores[25], sometimes equipped with diatons, able to contain the perimeter masses through efficient clamps and transfer the loads to the foundations;
- pyramidal distribution of the masses[26];
- realization of tapered walls on one or both sides able to contain the compression flows and easily lead them to the bottom of the masonry[27];
- presence of cantonal walls and effective wall hangings;
- the mass of structures, which although constituting an amplifying factor for seismic forces, assumes undisputed effectiveness in terms of shear resistance[28].

However, these aspects are not easily identifiable in poor architectures, often subject to inattentive superfetations able to cancel, in some cases, the original constructive memory. This partially happened in the village of Castel d'Alfero.

Furthermore, no efficient anti-seismic measures have been introduced in the past years. Reinforced concrete kerbs constitute a case in point: probably used for the purpose of protection

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[22] Here, *technology* means everything that derives from the invention of man and that alters the natural behavior of an element/system, while *technique* means all those procedures that derive from the application of laws inherent in materials and in the mechanics that characterizes them and that lay the foundations in scientific or empirical knowledge of the natural behavior of any system.

[23] Cangi 2014; *Tecniche antisismiche nell'antichità*, in: *Attualità delle Aree Archeologiche - Esperienze e proposte*, curated by Alessandra Centroni and Maria Grazia Filetici - Cangemi Editore.

[24] In the case of the Roman structures, for example, Giovanni Cangi observes that we can witness «*un uso sistematico di strutture spingenti, secondo un criterio che segue l'intero processo costruttivo, […] L'obiettivo è la ricerca di stabilità, soprattutto sotto l'effetto di azioni dinamiche, come quelle generate dal sisma. L'esperienza indica che in queste condizioni, contrariamente al pensiero comune, si dimostra più stabile una struttura spingente, se ben contrastata, rispetto ad una struttura non spingente. […] Ne sono prova le numerose costruzioni antiche dalla configurazione spingente, che si conservano ancora integre dopo aver sopportato numerosi e gravosi collaudi*», Cangi 2014, pp141-151.

[25] The core is that part of the structure with the task of retaining the perimeter masses, absorbing the seismic actions of the entire structure to lead them to the foundation.

[26] A modal analysis conducted on a building with pyramidal distribution of masses would provide results such that the distribution of forces associated with the first mode of vibration takes on an almost pyramidal or homogeneous form.

[27] The tapering of the walls and the truncated pyramid shape have, among other things, the purpose of giving stability to the building, keeping the centre of gravity at the bottom.

[28] The reduction of the mass is certainly aimed at containing the seismic forces, however it involves a simultaneous loss of the resistant capacities due, for example, to the reduction of the state of compression in the masonry able to increase the resistance to shear and out-of-floor bending.

against seismic actions, they almost always do not constitute boxlike profiles[29], increasing vulnerability of the system. In this sense, they are anomalous elements, often not connected to existing structures and therefore ineffective, as well as potentially harmful.

Given the morphological and constructive characteristics of the site, the reasons why Castel d'Alfero stood the test of time are therefore to be traced back, let us suppose, to the mutual relationship between the constituent units which, although increasing the vulnerability of the external units, have given to those placed internally a further contribution of stability with respect to the horizontal actions. Furthermore, the decent conservation status of constituting stone materials and binders is proof of good mechanical characteristics.

In case of interventions aimed at the improvement of complexes such as Castel d'Alfero, first of all, verified the nature of soils as well as the vulnerability of walls towards out-of-plane mechanism, ie overturning of the facades, permanent or temporary restraining systems should always be set up, without altering the structure of the artifact, aiming at least towards actions able to bring the behavior of historical walls to that of monoliths, and ensuring an efficient connection between floors and perimeter closures. This lead to a box-like behavior[30].

Nowadays we have reached awareness, at least in the field of research, learning from the construction techniques of antiquity, that the earthquake, as a natural phenomenon, is an integral part of the life of a building and it is necessary to accept, as it were, the damage that it causes. Actually, most up-to-date design approaches are oriented towards "accepting" the damage, which, however, can be conveniently located in specific points of the building[31]. Thereby, it is possible to check the eventual collapse modes and, at the same time, contain them with appropriate structural systems.

In the mentioned historical contexts, however, it is often difficult to identify areas in which it is easy to locate damage caused by the earthquake or, better said, to rely on ductile collapse mechanism[32]. It is necessary, instead, to use only “elastic resistance” of the masonry systems, which therefore must be increased when necessary.

It should be noted, however, that the executive and procedural feasibility is often limited, in addition to the morphology of the site and the vulnerability of the buildings, especially the availability of traditional materials, which represents a central issue in restoration field: if not far from Castel d'Alfero there still are extractive areas capable of providing marly sandstones with characteristics similar to those used in the abandoned village[33], not so much can be said for many other realities of the Romagna Apennines where the quarry activity is limited or even suspended.

Moreover, reaching these places with the necessary means for the execution of a construction site is often very hard: in many cases it is only possible by means of small machinery and transport limiting the field of possible executive operations. Condition that further complicates in some sites, such as the one in question, designed for animal-traction traffic and where the width of the roads or access routes was functional to these means.

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[29] Curbs, when well made, contribute to conferring a box-like behavior to the building. If they are not a closed profile, on the contrary, they represent an additional weight, often exacerbated by the lack of grips, which induces sliding with respect to the underlying masonry or lifting of the curbs themselves in the case of horizontal acceleration.

[30] Guerrieri 2001; Carocci et al. 2004; Boscotrecase, Piccarreta 2009; Cangi 2009, 2010 e 2012; Borri et al. 2011; Donà, De Maria 2011; Mariani 2012; Mastrodicasa 2012.

[31] Consider, for example, the principle of hierarchy of resistances: this methodology allows to place exactly the areas of dissipation of seismic energy, therefore affected by the damage and by greater deformations because of ductile behavior.

[32] Ductility is the ability of a material to develop large deformations before breaking.

[33] Think of the quarries of Fosso Abbacini in Magnano, near Castel d'Alfero: <http://www.comune.sarsina.fc.it/modulistica/urbanistica/pae/8c_ambito_estrattivo_15s_caste_d'alfero_fosso_abbacini.pdf>, 17.05.2018.

Therefore, due to the issues highlighted, it is necessary to understand how to limit, or at least make easy, actions aimed at increasing the resistance of the components. In this regard, the use of insulation and damping systems, for which reference should be made to the specialized literature[34], would represent a valid contribution to limit the effects of the earthquake on the building and subsequent operations aimed at increasing resistance. These systems respectively induce a change in the dynamic characteristics of the artefacts themselves and a mitigation of the seismic action[35]. However, they appear to be particularly difficult to be performed in historicized contexts such as those in question and consequently impractical[36].

4. An ongoing experimentation: metamaterials, metabarriers to work on the boundary.

Recently, there has been significant progress on the study of seismic waves, material testing, and possible new methods to reduce damage produced by dynamic actions. What is of particular interest here are those methods that propose to pursue solutions 'around' structures that may become significant in contexts where direct intervention to the building(s) is difficult and widespred[37].

In recent years, research institutions have studied seismic protection systems to be installed around the protected contexts in order to contain and minimize direct interventions on structures. These are barriers composed of "*metamaterials*", able to get into "resonance", amplifying their movements at certain frequencies of seismic vibration so to reduce the impact on the buildings to be protected.

"Metamaterials" are not a recent invention[38]. Their study started in 1987[39] with a research conducted by Eli Yablonovitch and Jhon Sajeev[40] proving how periodic optical structures can manipulate the light propagation through permitted and forbidden electronic energy bands. Generally, "metamaterials" are defined as artificial materials that are designed to have innovative properties not usually found in nature. Their properties are derived from their physical macrostructure[41]. Therefore, "metamaterial" are artificial media structured on a size scale comparable to the wavelength of the wave propagation phenomena they influence. Initially tested for the control of electromagnetic waves and then of the sonic waves[42], "metamaterials" have become the object of study on a geophysical scale for the mitigation of elastic waves, and particularly seismic waves. In the seismic field, however, it is difficult and onerous to create "metamaterials" with dimensions comparable to the typical

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[34] Chopra 2000; Kelly 2001; Martelli et al. 2008; Giovannardi, Guisasola 2010; Foti, Mongelli 2011.

[35] The isolation systems amplify the period of vibration of the structure, thus reducing the acceleration of the masses; the damping systems, on the other hand, do not modify the fundamental period of the structure, but reduce the effects of the seismic action itself, absorbing a good part of the energy that the seismic phenomenon transmits to the structure.

[36] An ordinary system of insulation of the entire building includes, for example, the insertion of an additional floor below the existing one.

[37] We are thinking not only of inhabited complexes, but also of realities in the state of ruins of high historical significance as archaeological sites.

[38] Although the term was only coined later, in 1999, by Rodger M. Walser of the University of Texas in Austin.

[39] Yablonovitch 1986; Sajeev 1987. At first, photonic crystals were discovered, periodic structures capable of modifying the propagation of light by creating frequency bands where the propagation of the electromagnetic wave does not occur, called bandgaps (or prohibited band).

[40] Yablonovitch 1986; Sajeev 1987. At first, photonic crystals were discovered, periodic structures capable of modifying the propagation of light by creating frequency bands where the propagation of the electromagnetic wave does not occur, called bandgaps (or prohibited band).

[41] In other words, a metamaterial gains its properties from its structure rather than directly from its chemical composition. In particular, such structures generally have dimensions comparable to or smaller than the wavelength of the phenomenon they affect.

[42] Lu et al. 2009.

wavelengths of this phenomenon, that varies between meters and decameters. For example, it would be difficult to install a barrier of similar dimensions below the ground surface in the contexts under study. Thus, in the field of seismic protection, the research has been focused on the experimentation of locally resonant structures, with smaller dimensions, that are able to attenuate the waves due to the collective effect of the resonators[43], instead of periodic layout. The local resonant behavior is very simple: the seismic wave is a perturbation that carries energy through a medium, precisely the ground, with a certain frequency. The ground acts as a conductor, allowing for the passage of the waves and their energy. Resonant "metamaterials" confer to the propagation medium isolation characteristics at certain frequencies. Therefore, the wave is not transmitted in the frequency range related to the resonators natural frequency. In recent years, there have been several studies proving the validity of seismic "metamaterials", such as the "meta-barrier" proposed by Antonio Palermo and Sebastian Krödel[44], which is capable of converting surface elastic waves (Rayleigh's seismic waves) into volume waves, which are less harmful for civil structures[45].

The present research can be identified as part of the Metaforet project[46], a large-scale wave experiment which aims to demonstrate how a forest could act as a seismic metamaterial, by considering the individual trees as locally resonant structures able to attenuate and divert the seismic waves. This research could potentially assume a very important role in the future design of "metabarriers" to protect structures from seismic actions, especially in historical contexts. Therefore, it is relevant to this paper to report the main characteristics of the Metaforet experiment. The experiment took place in the Landes forest, located in south-western France, characterized by a density of pine trees equal to 800 trees per hectare. Within this forest, the propagation of Rayleigh seismic waves[47] was simulated by elastic waves generated by a shaker with a frequency range between 1 and 100 Hz. The wave propagation was recorded between the forest and an open field, through a mesh of 1000 geophones, as shown in Figure 7. The experiment confirmed the strong influence that a dense plant system can have on the seismic wave propagation[48].

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[43] The dimensions of the resonators are generally always smaller than the wavelength relative to the phenomena that influence and to be effective the distance between the individual elements must be at least less than half the wavelength in question.

[44] Palermo et al. 2016. The meta-barrier in question consists of cylindrical masses supported by elastomeric springs that act as resonators along their vertical axis.

[45] Volume waves, divided into P and S waves, have shorter periods of vibration than surface waves, divided into Rayleigh and Love waves. The latter can therefore cause even very slow and wide oscillations that appear particularly harmful to buildings. In addition, surface waves are the result of the combination of volume waves and are therefore much more complex. It should also be remembered that surface waves disperse much less quickly than volume waves: for this reason they can cause significant damage even at great distances from the source of propagation.

[46] Roux et al. 2018.

[47] Rayleigh's seismic waves, together with Love's seismic waves, represent the main superficial seismic waves responsible for the great damage caused by earthquakes on civil structures. The passage of Love's waves takes place in the horizontal plane and is transversal with respect to the direction of propagation, while Rayleigh's waves make the ground vibrate according to elliptical orbits, in the vertical plane with respect to the direction of propagation of the wave.

[48] It has been possible to identify frequency bands where no wave propagation takes place. These specific frequency ranges are linked to the flexural (10 Hz) and longitudinal (40-50 Hz) vibration modes of the individual trees that make up the forest.

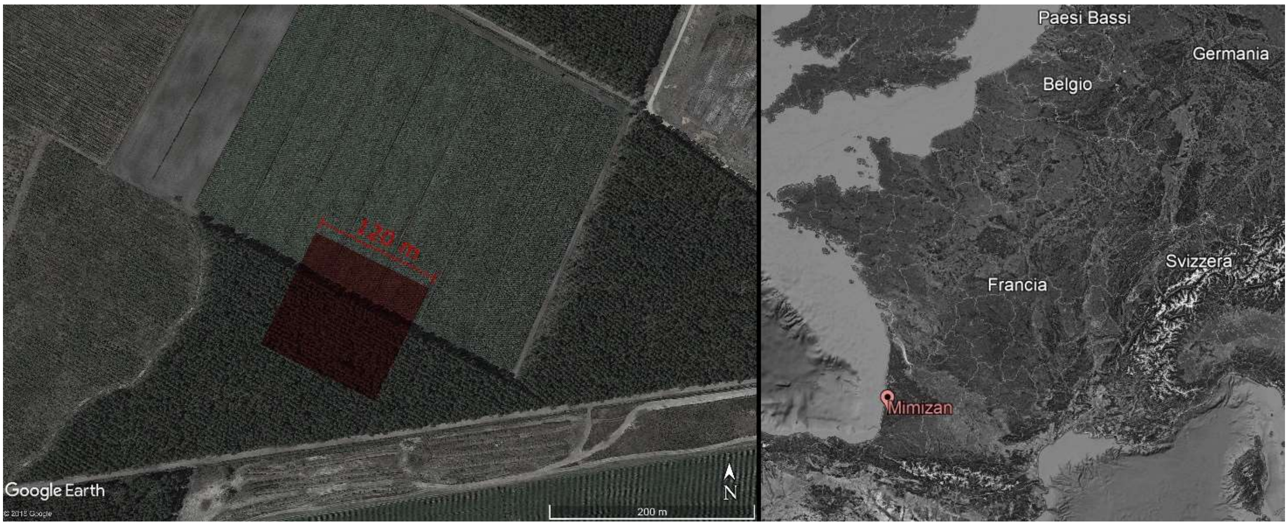

Fig. 7.

Using the results of the Metaforet project, the same experiment has been tried out numerically to study the phenomena, modeling the resonators with similar characteristics to the forest trees. The numerical simulation was performed on MATLAB using the spectral finite element method (SEM), which provides a numerical solution of partial differential equations with low computational cost. Because of the nodal interpolation given by the Gauss-Legendre-Lobatto polynomials, high accuracy is achieved with a limited number of nodes. The implemented code analyzes the phenomena in the time domain and, due to its effectiveness, a sensitivity analysis of the main parameters has been easily performed. Thus, it has been demonstrated that the most influential parameters are the number and spacing of individual elements: increasing the number of resonators and reducing the spacing between adjacent elements the metamaterial barrier improves its efficacy. This phenomena is shown in Figure 8. where the results are reported in terms of wave propagation[49] for certain frequencies with varying spacing between the elements. Moreover, there is a frequency range in which no wave propagation takes place.

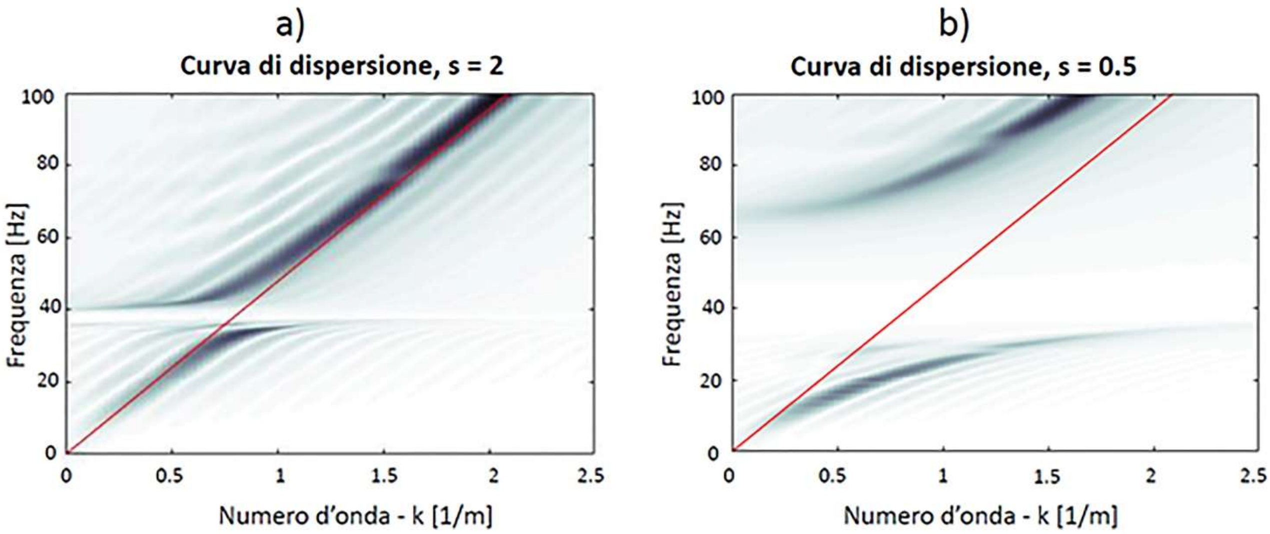

Fig. 8.

[49] Leakage curve in a two-dimensional propagation field, e.g. the surface of the ground.

Contrarily, the type of source and the order of the elements do not influence the response of the resonators. Research on the use of resonator barriers is proceeding with the aim of obtaining effective products in relating to the resonance frequencies most dangerous for civil buildings, while economically and environmentally sustainable[50].

5. Concluding considerations.

As was pointed out, the research aimed at preserving realities such as the medieval village of Castel d'Alfero is decidedly very complex, due to the nature of the processes of assessing the vulnerabilities of aggregates. Consequently, the actions, representing the choice of "a possible", require critical processes based on the awareness of the intrinsic 'fragility' of the historical heritage as well as the responsibility of those who make conservative or restoration choices. Choices that require comparisons between different disciplines. For example, the impact of the processes aimed at seismic improvement must be evaluated "parametrically", making assessments of archaeological, architectural, structural and, in any case, economic and logistical nature in relation to site operations, thrashing beforehand and with extreme care all the "secondary" processes related to an executive procedure. In this regard, consider how a 'simple' operation aimed to the increase of the dynamic performance of a floor (stiffening and connection with walls), implies a series of interventions to a "system" that necessarily undergoes changes (consolidation of walls, increase of working loads on foundations and, sometimes, consequent construction of sub-masonry) at the stratigraphic, architectural and structural levels. Thus, this imposes on those who are called to make such decisions the awareness of their work and the safeguard of future interpretations of the intervention itself, after restoration.

It should also be emphasized that the state of art that characterizes historical buildings, i.e. local technical knowledge based on empirical experience, are often put aside because their memory has been lost, or even, because they are not profitable, or because they often escape calculation methods due to the heterogeneity of construction that constitutes the techniques and historical buildings.

[50] Colombi et al. 2016. Currently numerical simulations with artificial metamaterials with dynamic properties similar to those shown by the vegetable resonators of the Landes forest (therefore able to enter into resonance at the frequencies of vibration generated by the earthquake) generate propagation interruptions, called bandgaps (forbidden bands), especially with regard to the Rayleigh waves. The goal, in the near future, is to test solutions that also include the waves of Love in order to obtain bandgaps large enough.

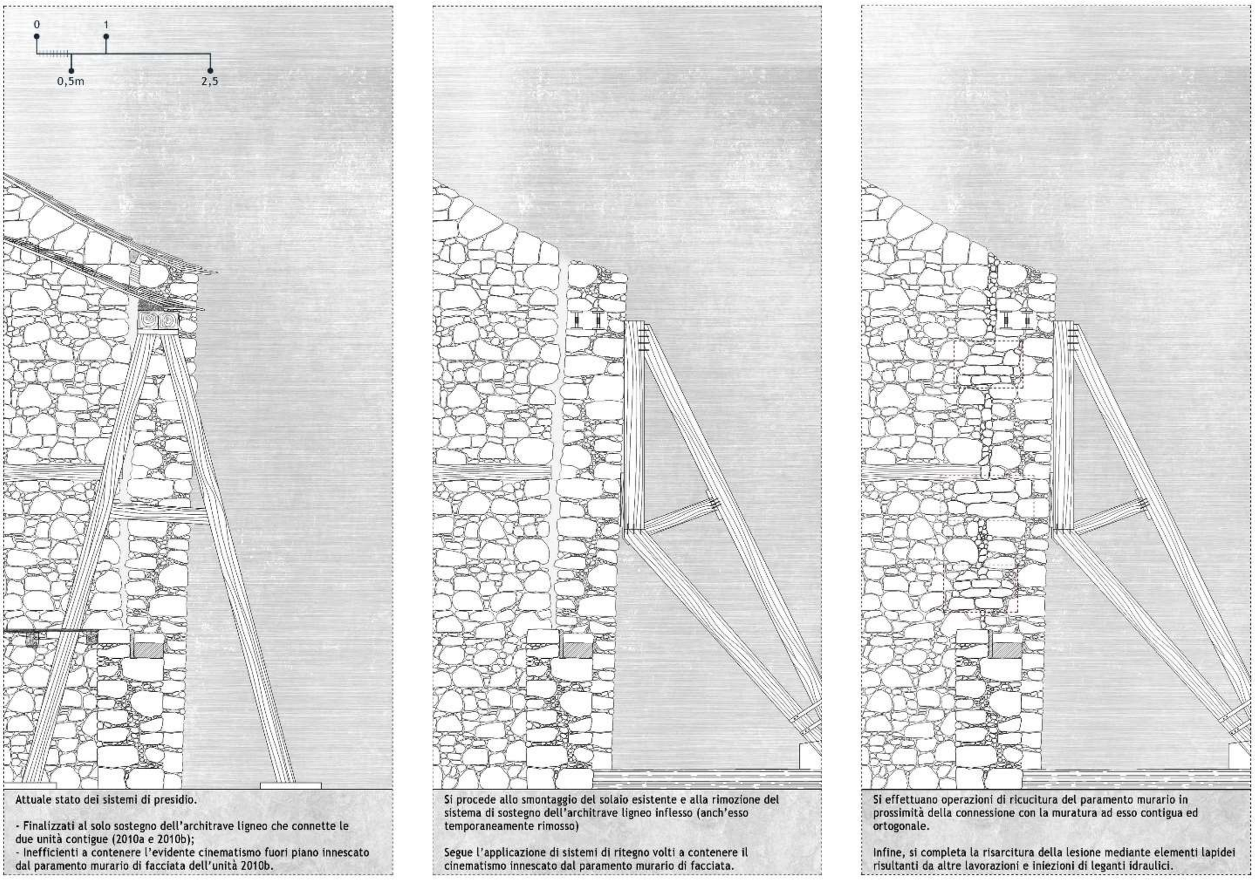

Fig. 9

Therefore, if it will always be necessary to take care of and defend historical buildings with the resources and tools at our disposal, it is equally true that new areas of research are opening up, the results of which would lead to lower direct interventions on ancient buildings, facilitating conservation practices and the recovery of traditional techniques which generally have less impact on the ancient built.

The combined effects of artificial and natural barriers, as demonstrated by French and Italian researchers, could represent, in this regard, an important "anti-seismic device". In fact, we have seen how a system of resonators, characterized in this case by pine trees, can give to the means of transmission of seismic waves "insulating" capabilities, producing "forbidden bands" of frequency.

The next step of this study, dealing with the conservation of the built heritage, could be the assessment of the actual impact that forests and/or artificial resonators[51], located in the immediate surroundings of structures, archaeological sites and abandoned villages can achieve when a seismic event occurs. An analysis could initially be carried out by means of numerical methods, knowing, with a good margin of precision, the resonant properties of the vegetation surrounding the buildings analyzed. The aim of such a survey would be to verify whether over time the morphology of the territory has generated, so to speak, "spontaneous" forbidden bands reconstructing historical seismicity of the site.

[51] However, in the case of artificial resonators, the possibility of their installation must be assessed in relation to the nature of the soil and its conformation.

The results of this research, still in progress, could potentially represent an interesting starting point to implement the variability of confidence factors in the procedures for assessing seismic vulnerability, considering not only the construction characteristics of the architecture but also the related boundary conditions, such as the presence of a forest: we would like to think actually, even if we do not yet have the objective evidence, that the survival of the village of Castel d'Alfero has been made possible, in addition to the nature of its built and rocky sediments on which it is located, also by the vegetation that surrounds this precious reality of the Romagna Apennines.

Fig. 10

Riferimenti bibliografici / References.

Berardi D. Cassi Ramelli A., Foschi M., Montevecchi F., Ravaldini G., Venturi S (2000). *Rocche e Castelli di Romagna,* vol.2, Bologna: University Press.

Berardi R. (2000). *Interventi di Ingegneria Geotecnica nella Salvaguardia del Territorio,* Atti Convegno "Ambiente e (CD ROM, intervento 1.11).

Berardi R. (2017), *Fondamenti di geotecnica*, città: Città Studi Edizioni, UTET Università.

Binda L., Cardani G., Modena C., Saisi A.E., Valluzzi M.R. (2005), *Studio della vulnerabilità degli edifici dei centri storici in zona sismica*, in *Tecniche costruttive dell'edilizia storica*. *Conoscere per conservare*, a cura di D. Fiorani, D. Esposito: Viella Editore, pp. 17-30.

Blasi C., a cura di (2013), *Architettura storica e terremoti: protocolli operativi per la conoscenza e tutela*, Assago: Wolters Kluwer Italia.

Borri A., Cangi G., De Maria A. (2007), *Studio sulla vulnerabilità sismica del patrimonio edilizio. Il centro storico di Gubbio*, Atti del XII Convegno Nazionale dell'Associazione Nazionale Italiana Di Ingegneria Sismica (ANIDIS) *L'ingegneria sismica in Italia* (Pisa, 10-14 giugno 2007), CD-Rom.

Borri A., Cangi G., De Maria A. Donà C. (2011), *Metodi qualitativi per la valutazione della qualità muraria*, in *Manuale delle murature storiche*, 2 voll., a cura di C. Donà, Roma: Collana Centro Studi Sisto Mastrodicasa, DEI Editore, vol. I, pp. 236-294.

Boscotrecase L., Piccarreta F. (2009), *Edifici in muratura in zona sismica, Nuove costruzioni – Consolidamento dell'esistente, La teoria e la tecnica*, Palermo: Ed. Dario Flaccovio.

Brogiolo G.P., Cagnana A. (2012), *Archeologia dell'Architettura. Metodi e interpretazioni,* All'Insegna del Giglio, Firenze.

Cabras F. (2018), *Forests as a natural seismic metabarrier: analysis of interaction between trees and Rayleigh waves,* tesi di laurea magistrale in ingegneria civile, Alma Mater Studiorum, Università di Bologna, aa.2016-2017, relatore prof. A. Marzani.

Cangi G. (2009), *Murature tradizionali e terremoto. Analisi critica del danno come presupposto per il recupero e la ricostruzione dell'edilizia storica danneggiata dal sisma in Abruzzo*, in *Reportage dall'Abruzzo 2*, Convegno di studi (Firenze, 23 ottobre 2009), Firenze.

Cangi G. (2010), *Analisi strutturale per il recupero antisismico. Calcolo dei cinematismi per gli edifici in muratura secondo le NTC,* Roma: DEI Editore.

Cangi G. (2012), *Manuale del recupero strutturale e antisismico,* Roma: DEI Editore.

Cangi G. (2014), *Tecniche antisismiche nell'antichità*, in *Attualità delle aree archeologiche – Esperienze e proposte*, a cura di Centroni A., Filetici M.G. (2014), Roma: Gangemi Editore.

Carocci C.F., Ceradini V., Cremonini I., Panzetta M., Mazzotti P., Smargiasso M. (2004), *Recupero e riduzione della vulnerabilità dei centri storici danneggiati dal sisma del 1997*. (Rassegna ragionata dei programmi di recupero post sisma. Attività di ricerca promossa dal Comitato Tecnico Scientifico per la ricostruzione post sisma nelle Marche), Regione Marche, Ancona.

Carocci C.F., Copani P., Marchetti L., Tocci C. (2014), *Vulnerability reduction procedures in ordinary urban management. The Urban Building Code of Faenza*, in International Conference *Structural Monitoring of ARTistic and historical BUIlding Testimonies* (Bari, 27-29 marzo 2014), a cura di D. Foti: Key Engineering Materials Vol. 628, Trans Tech Publications, Cap. 2: Structural Area, pp. 61-66.

Carocci C.F., Marino M. (2009), *Gli aggregati murari della città storica: conoscenza e interpretazione per la valutazione della vulnerabilità sismica*, in *L'ingegneria sismica in Italia,* Atti del XIII Convegno Nazionale dell'Associazione Nazionale Italiana Di Ingegneria Sismica (ANIDIS) (Bologna, 28 giugno - 2 luglio 2009).

Chopra A. K. (2000), *Dynamics of Structures*: Prentice Hall.

Colombi A., Colquitt D., Roux P., Guenneau S. and Craster R. V. (2016), *A seismic metamaterial: The resonant metawedge,* «Scientific Reports», 6, n. 27717.

Corzani G. (1988), Piano di recupero di Castel d'Alfero, <http://www.provincia.fc.it/pianificazione/psc2006/Sarsina/Sistema%20insediativo%20storico/centro_storico/Relazione_Castel_Alfero_CS_1A.pdf>, 28.05.2018.

Della Torre S., a cura di (1996), *Storia delle tecniche murarie e tutela del patrimonio. Esperienze e questioni di metodo*, Milano: Guerini Studio.

De Luca M., *I sistemi insediativi di alto promontorio: l'aggregato urbano di Castel d'Alfero. Analisi dello stato di Conservazione, rilievo dei cinematismi in atto, progetto di restauro e riuso,* tesi di laurea magistrale in architettura, Alma Mater Studiorum, Università di Bologna, aa.2014-2015, relatore prof. A. Ugolini.

Donà C., De Maria A., a cura di (2011), *Manuale delle murature storiche,* Roma: DEI Editore, Voll. 1-2.

Formisano A. (2013), *Usability check and seismic vulnerability of a cultural heritage masonry buildings damaged by the Emilia Romagna seismic event*, in Proceedings of the SE-50EEE International Conference on *Earthquake Engineering* (Skopje, Republic of Macedonia, 29-31 may 2013), pp. 1-8.

Foti D., Mongelli M. (2011), *Isolatori Sismici per Edifici Esistenti e di Nuova Costruzione*, Palermo: Ed. Dario Flaccovio.

Giovannardi F., Guisasola A. (2010), *Base isolation: dalle origini ai giorni nostri*: Adepron.

Giuffrè A. (1991), *Letture sulla meccanica delle murature storiche,* Roma: Kappa.

Giuffrè A., a cura di (1993), *Sicurezza e conservazione dei centri storici. Il caso Ortigia: codice di pratica per gli interventi antisismici nel centro storico*, Roma: Edizioni Laterza.

Giuliani Cairoli F. (2011), *Provvedimenti antisismici nell'antichità*, «JAT», 21, pp. 25-52.

Grimoard de Anglic, Descriptio Romandiole 1371, in L Mascaroni La "Descriptio Romandiole" del Card. Anglico Soc. Studi Romagnoli, ristampa edita da Fotocromo Emiliana, Cesena.

Guerrieri F., a cura di (2001), *Manuale per la riabilitazione e la ricostruzione post-sismica degli edifici*, Roma: DEI Editore.

Kelly T. (2001), *Base Isolation of Structures – Design Guidelines*, Wellington: Holmes Consulting Group ltd.

Lagomarsino S., Ugolini P., a cura di (2005), *Rischio sismico, territorio e centri storici*, atti del Convegno nazionale, (Sanremo – Imola, 2-3 luglio 2004), Milano: F. Angeli.

Lu M.H, Feng L., and Chen Y. (2009), *Phononic crystals and acoustic metamaterials*, «Materials Today», 12, n. 12, pp.34-42.

Mariani M. (2012), *Trattato sul consolidamento e restauro degli edifici in muratura*, Roma: DEI Editore.

Martelli A., Sannino U., Parducci A., Braga F. (2008), *Moderni sistemi e tecnologie antisismici. Una guida per il progettista*, Milano: 21mo secolo.

Mascanzoni L. (1985), *La «Descriptio Romandiole» del card. Anglic. Introduzione e testo*, Bologna: La Fotocromo Emiliana.

Mastrodicasa S. (2012), *Dissesti statici delle strutture edilizie,* Milano: Hoepli.

Palermo A., Krödel S., Marzani A. e Daraio C. (2016), *Engineered metabarrier as shield from seismic surface waves,* Scientific Reports, 6, Article number: 39356.

Pracchi V., a cura di (2008), *Lo studio delle tecniche costruttive storiche: stato dell'arte e prospettive di ricerca*, Como: NodoLibri.

Roux P., Bindi D., Boxberger T., Colombi A., Cotton F., Bacque I. D., Garambois S., Gueguen P., Hillers G., Hollis D., Lecocq T. and Pondaven I. (2018), *Toward seismic metamaterials: The metaforet project*, «Seismological Research Letters», XX, n. 20, pp.1-12.

Sajeev J. (1987), *Strong localization of photons in certain disordered dielectric superlattices*, «Physical Review Letters», 58, n. 23, pp. 2486-2489.

Scalora G., Monti G. (2010), *La conservazione dei centri storici in zona sismica – un metodo operativo di restauro urbano,* Milano: Academia Universa Press.

Yablonovitch E. (1986), *Inhibited spontaneous emission in solid-state physics and electronics*, «Physical Review Letters», 58, n. 20, pp. 2059-2062.

Zamboni I. (2017), *Tecniche speditive di rilievo stratigrafico per la valutazione della vulnerabilità sismica degli aggregati storici in muratura. Caso studio: Civita di Bagnoregio (VT)*, tesi di dottorato, Università IUAv di Venezia, XXX ciclo a. a. 2016-2017, relatore P. Faccio, prof.ssa A. Saetta, prof. M. Piana.

Zordan L., Bellicoso A., De Berardinis P., Di Giovanni G., Morganti R. (2009), *Le tradizioni del costruire della casa in pietra*, Città di Castello: Alinea.

Appendice:

Fig. 1. Drawings of Castel d'Alfero, by Architect G. Corzani.

Fig. 2. Castel d'Alfero: general plan at the level of ground floor.

Fig. 3. Photogrammetrical relief of facades at Castel d'Alfero: buildings placed to the west. Note the accentuated slope f the ground.

Fig. 4. Castel d'Alfero (SA): presidia aimed at the protection of buildings against kinematics mechanism.

Fig. 5. Castel d'Alfero (SA): Example of incorrect evaluation of the provisional structures necessary for securing. Faced with the urgent need for restraint systems, which are able to contain the kinematic mechanisms of the masonry, only support structures have been installed for vertical actions.

Fig. 6. Castel d'Alfero (SA): view of the downstream aggregate system. Planimetry shows lack of regularity and delineates often narrow paths.

Fig. 7. Top view of the forest used in the Metaforet experiment: the highlighted area represents the position of the seismometers.

Fig. 8. Dispersion curves obtained in the two-dimensional domain with a metabarrier composed of equispaced resonators every 2 meters (a) and every 0.5 meters (b). In case of uniform propagation, the dispersion curve assumes the appearance of a straight line. The graph, on the other hand, shows the bandgap (forbidden bands) induced in the means of propagation: in the case of resonators every 2 meters, waves with frequencies of approximately 35 to 40 Hz are not transmitted; in case of resonators every 0.5 meters, on the other hand, the bandgap is wider and not all waves characterized by frequencies between 30 and 65 Hz are transmitted.

Fig. 9. Proposed intervention, unit 2010 b Castel d'Alfero (according to the distinction proposed by the Municipal Structural Plan): in the proposed image are represented the main operations aimed at the retention of walls and the technique of "scuci-cuci", aimed at conferring monocrity to the wall facing.

Fig. 10. Castel d'Alfero (SA): view of the architectural unit downstream. The current state of abandonment risks inexorably compromising the integrity of an architectural system of great historical testimonial value, already strongly marked by time.