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Stone materials, processes and mortars in archaeosismology studies: the case of Mugello (Tuscany-Italy)

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Abstract

Mugello is an intermontane basin with medium-high seismic risk located in the Apennine Mountains on the border between Tuscany and Emilia Romagna. The territory is characterized by numerous long-lasting settlements which comprise well-preserved historical buildings. Between 2010 and 2014, an area of Mugello was involved in the project "Archaeology of architecture and seismic risk in Mugello", research focused on evaluating the archaeological analysis process as a form of prevention and protection of medieval buildings from seismic risk. This research describes the central role played by the study of the provenance, processing, and installation of the stone materials used for the construction and modification of architectural structures during the period twelfth to twentieth century. It also illustrates the potential that the study of bedding mortars can have in archaeosismology. These materials contain much technical information, starting from the raw materials used for their realization (stone for the production of lime, aggregate) to arrive at the mix design (binder/aggregate ratio, quantity of water). Therefore, their study makes it possible to contribute to the characterization of the masonries even when they are made with the same stone materials and worked in the same way.

Keywords: Archaeoseismology; Architecture; Building techniques; Chronotipology; mortars

Introduction

Mugello is a medium-high seismic risk area located in the Apennine mountain range on the border between Tuscany and Emilia Romagna. The territory has been continuously inhabited since the Middle Ages and is characterized by well-preserved historic buildings, most of which are religious buildings.

An area of Mugello between the municipalities of Scarperia, Borgo San Lorenzo, Vicchio and Barberino, was examined between November 2010 and March 2014 for a project entitled "Archaeology of architecture and seismic risk in Mugello". The project provided an archaeological analysis of medieval buildings in relation to their vulnerability to seismic risk (Arrighetti 2015). Among the results that emerged from archaeological investigations, considerations concerning the supply and use of building materials for the construction and modification of architectural structures played a central role during the period twelfth to twentieth century.

One of the most interesting aspects regarding the construction history of the buildings was the potential to identify, catalogue and in some cases to date the structural systems that characterize them. The sources used in the research were essentially two types: the first, historical sources, useful for providing the historical context and timeline for specific construction events; second, the stratigraphic reading of the exposed masonries, which provides insight on the construction phases of the analysed artifact. Therefore, this type of analysis made it possible to propose a characterization and dating of the anthropic operations of modification of the building due to natural events, such as earthquakes (Arrighetti 2022).

The chrono-typologies of the proposed construction systems made it possible to catalogue and date the different masonries. Once compared, these masonries offered the possibility of hypothesizing the use of specific expedients in their construction. At the same time, the definition of a chrono-typology

of restoration interventions in the seismic area led to hypothesize the role of workers and customers in the post-earthquake phases. This practice was found to be essential to hypothesize the presence or absence of a Local Seismic Culture (Pierotti-Ulivieri 2001; Pierotti 2003) in the know-how of the builders present in the area investigated.

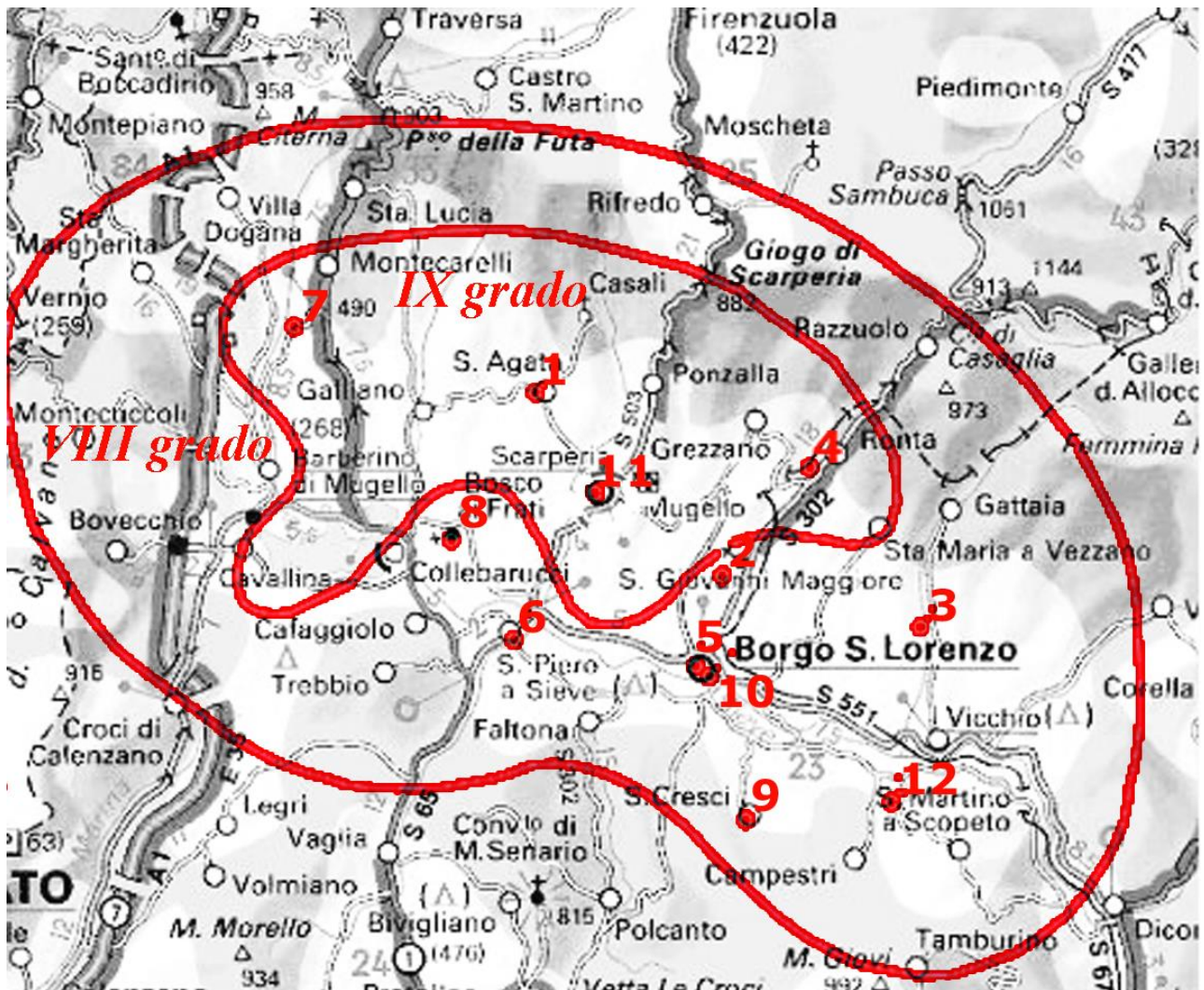


Figure 1 – The twelve buildings analyzed in the project and the boundary of the study context, the latter corresponding to the VIII degree of Macroseismic Intensity hypothesized by the National Institute of Geophysics and Volcanology for the 13th earthquake of June 1542 (FERRARI-MOLIN 1986).

Methodological lines and analysis of the artifacts

The project "Archaeology of Architecture and seismic risk in Mugello" was characterized by a methodology of context analysis based on the archaeological approach to the study of medieval architectural artefacts (Brogiolo-Cagnana 2012). A first systematic survey of the study area (Fig. 1) led to the identification of numerous buildings to be analysed. Then a total of twelve architectural complexes representative of the quality of the exposed masonry structures (capable of allowing a stratigraphic analysis of the construction phases) and representative of the period of interest (from the twelfth to the seventeenth century) were selected. The analysis was conducted by groups of construction activities, arriving at the identification of the Wall Stratigraphic Units only where it was necessary to deepen the detail of the research (Fig. 2).

The stratigraphic analysis was therefore followed by the construction of a relative chronology of the construction phases, which led to the first interpretation of the archaeological data and a chrono-

typological characterization of the individual masonry construction techniques present in the structures. Then a review of the published and unpublished written sources in local and national archives and libraries was conducted, making it possible to propose absolute chronologies for some phases. The final step was interpreting the processed data in relation to the twelve artifacts in a particular regional setting. Thus, it was possible to better understand the changes in the settlement dynamics of the area and the related social, economic and political aspects.

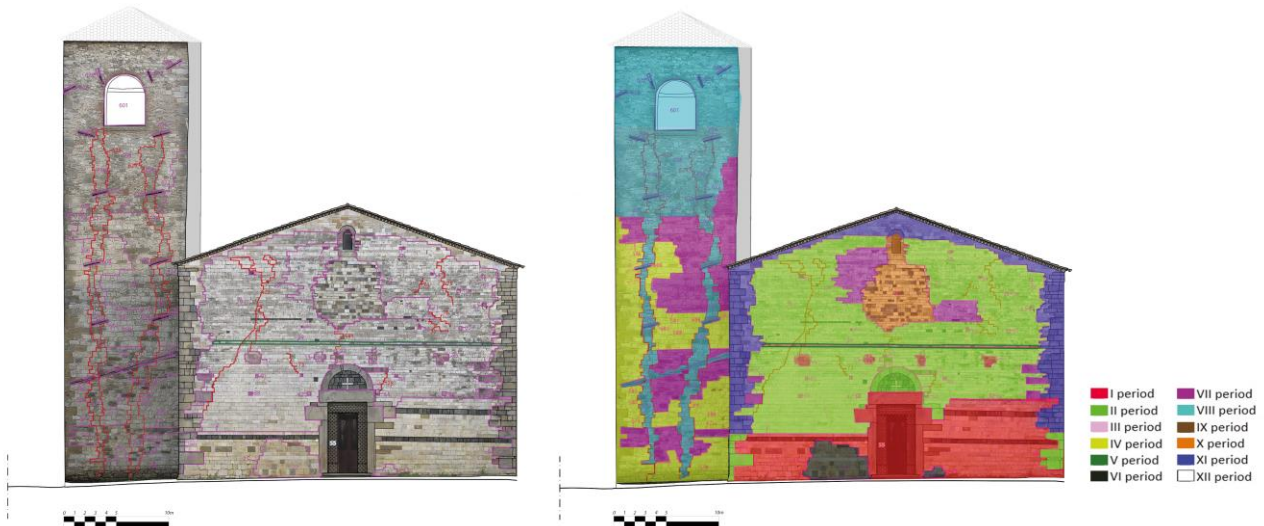


Figure 2 - The image shows an example of the stratigraphic reading carried out by Wall Stratigraphic Units (on the left) and groups of construction periods (on the right). In particular, the figure presents the stratigraphic analysis of the east elevation of the church of Sant'Agata del Mugello (FI).

The supply and use of building materials from the late Middle Ages and early modern age

The Mugello is morphologically defined by a depressed central area, crossed in its southern part by the Sieve River. This main area is made up of fluvial lacustrine terraces. To the north is the Apennine chain, consisting mainly of sandstone geological formations; to the south is the Monte Giovi - Monte Senario chain, consisting of sandstone formations in the eastern area and limestone marly formations (Pietra Alberese) in the western area (Fig. 3).

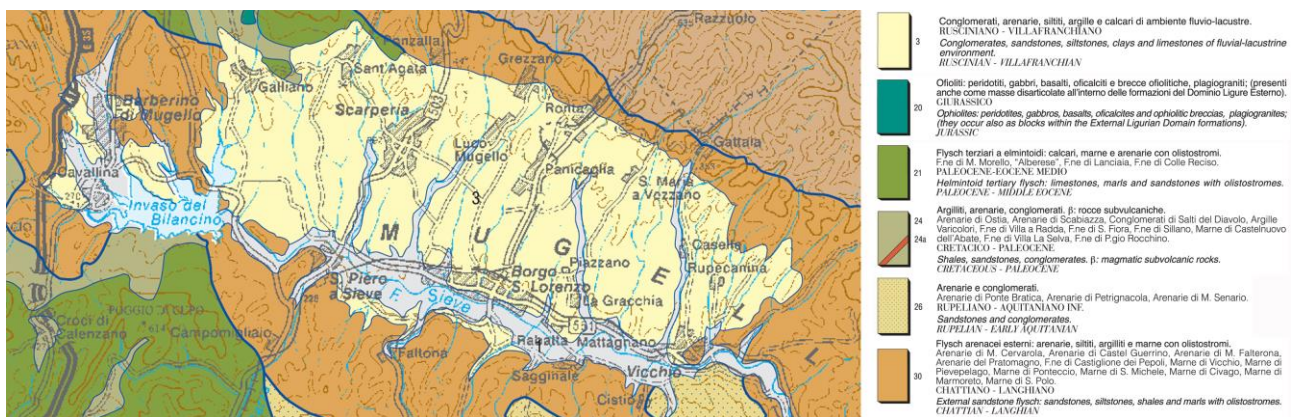


Figure 3 - Detail relating to the Mugello of the Geological Map of Tuscany (geological map 1:250,000 modified after Carmignani and Lazzarotto 2004).

These geological formations supplied the construction materials, represented by the Alberese stone (marly limestone) (Fratini et al 2020), the Pietra Serena (sandstone) (Fratini et al. 2014), the Monte

Senario sandstone (Cipriani et al. 2005), and clay for the bricks. To these materials, we should add the Green Marble of Monte Calvi (serpentine, Fig. 4) (Fratini et al. 2022) and the over-burned and vitrified bricks (Fig. 5) used sporadically as a decorative material.



Figure 4 - Chessboard composed of sketches of Green Marble from Monte Calvi and Pietra Alberese present on the north elevation of the Pieve di Sant'Agata del Mugello.



Figure 5 - Vitrified bricks present as a decorative element in the joints of the bell tower of the Pieve di San Giovanni Maggiore.

Finally, the presence of limestones and sandstones of the Sillano Formation is used as constructive materials, always together with the Alberese stone. By comparing the chrono-typological data, it is possible to identify four historical periods linked to construction moments of particular importance. Each phase seems to be characterized by the choice of one or more materials depending on factors of different nature, be they economic-political or simply practical. In particular, the use of construction materials falls within the following construction periods:

-1st period (10th-12th century): the choice of the stone materials seems to depend strictly on the lithologies present in the vicinity of the building rather than on the evaluation, by workers and clients, of the characteristics (constructive and decorative) of the various raw materials (Fig. 6). In this period, the buildings of almost all twelve religious structures involved in the research can be included. A clear demarcation is evident between Western Mugello with the use of Pietra Alberese and Eastern Mugello with the use of Pietra Serena and Monte Scenario sandstone.



Figure 6 - Building materials used in Mugello from the tenth to the twelfth century: Pietra Alberese (blue colour), Pietra Serena (magenta colour), and Monte Scenario sandstone (cyan colour) (geological map 1:250,000 modified after Carmignani and Lazzarotto 2004).

-2nd period (13th-14th century): starting from the first half of the thirteenth century, a new construction material began to be used: bricks from a particular area of the Mugello region. The bricks were for a religious client that probably employed specialized workers. The hypothesis of a possible interaction between the introduction of the new construction material in Mugello and the presence of non-local workers seems confirmed by the stylistic and archaeological analysis of the bell tower of the Pieve di Borgo San Lorenzo, whose architectural typology, as already hypothesized by other scholars (Moretti and Stopani 1974), could suggest influences coming from the Lombard region (Figs. 10 and 11).

In the rest of Mugello, there is a continuity in the use of Pietra Serena and Pietra Alberese (Fig. 7). The phenomenon is probably linked to the constant exploitation of the same supply areas for the raw materials, perhaps related to the presence of the same workers and clients of the previous period.

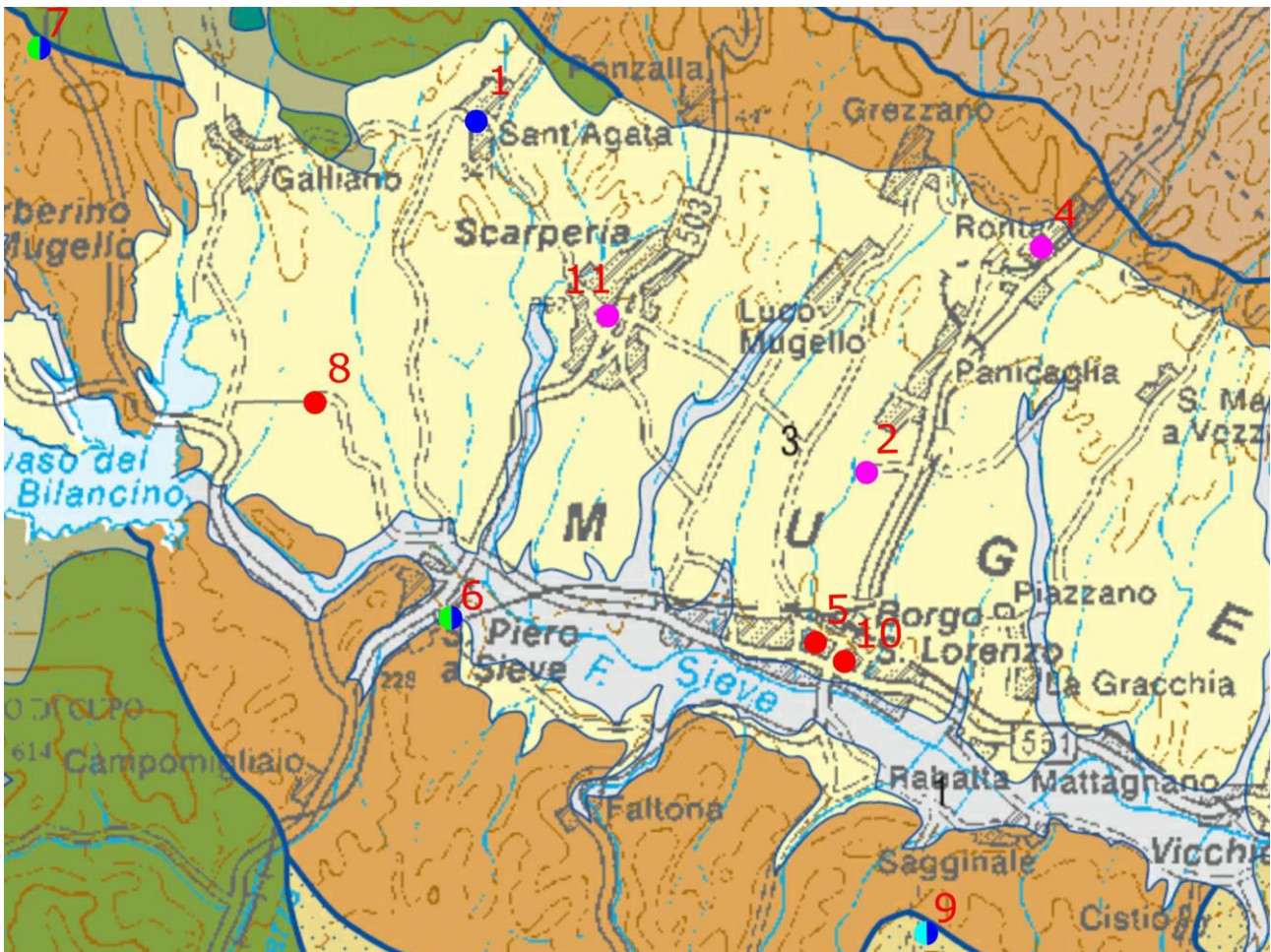


Figure 7 - Building materials used in Mugello from the 13th to the 14th century: Pietra Alberese (blue colour), Pietra Serena (magenta colour), Brick (red colour), and Monte Senario sandstone (cyan colour) (geological map 1:250,000 modified after Carmignani and Lazzarotto 2004).

-3rd period (15th century): this period is a transition between two great construction moments affecting the Mugello area, namely the extensive restorations carried out in between the thirteenth and fourteenth centuries and the post-seismic reconstructions from 1542 to the first half of the seventeenth century. There is a continuity in the use of stone materials in the areas described in the first period, flanked by an introduction of bricks for some restorations carried out in the Palazzo dei Vicari in Scarperia (Fig. 8). In the latter case, a link between a very wealthy client, the Medici family, and the specialized workers involved in the construction of bricks during the second period can be hypothesized.

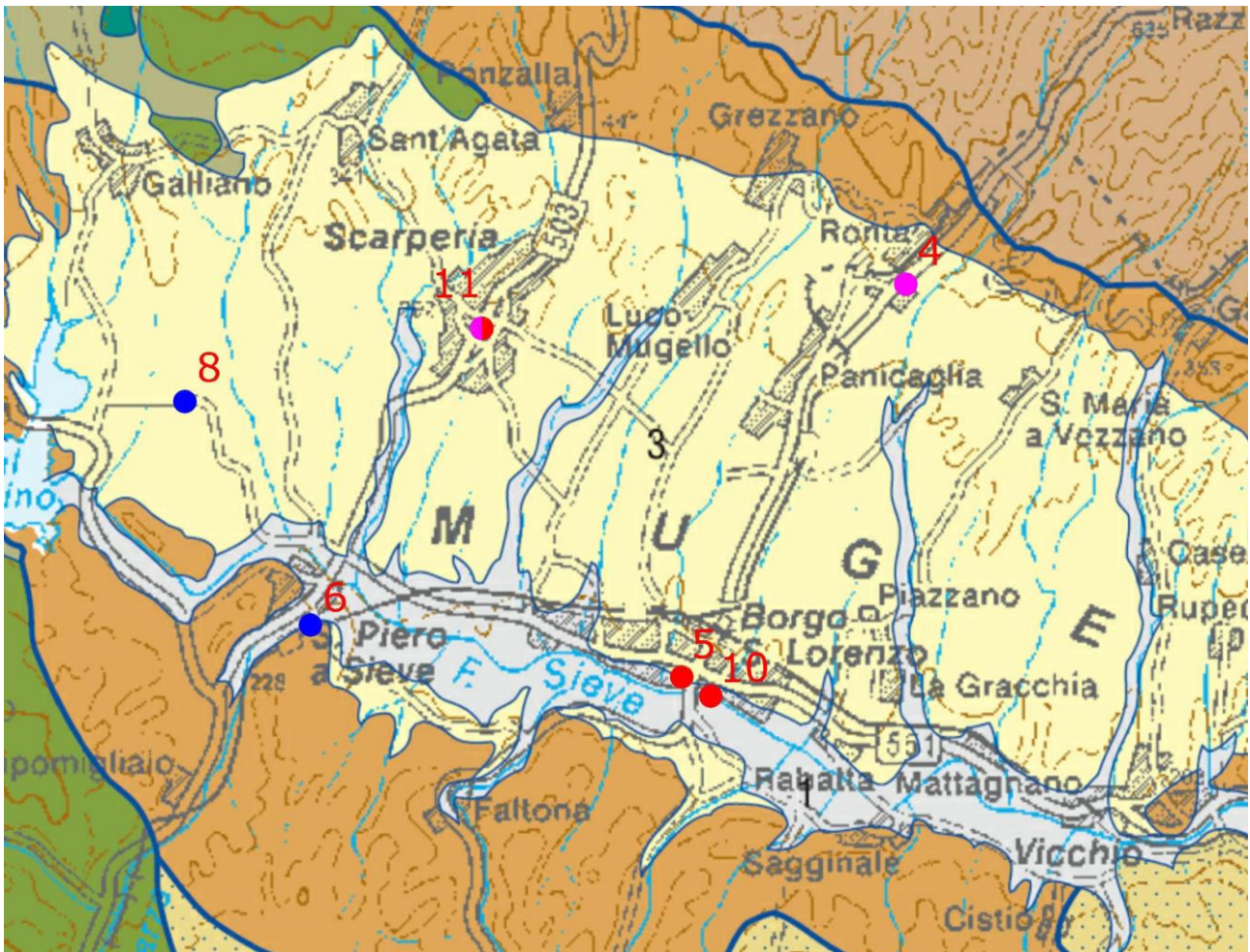


Figure 8 - Building materials used in Mugello in the 15th century: Pietra Alberese (blue colour), Pietra Serena (magenta colour), and brick (red colour) (geological map 1:250,000 modified after Carmignani and Lazzarotto 2004).

-4th period (16th - early 17th century): the restorations and reconstructions carried out following the earthquakes of 1542, 1597, and 1611 date back to this period. It is interesting to note the abandonment of the Alberese stone, in contrast to the extensive use of the Pietra Serena and bricks (Fig. 9). The reason for this preference is unclear. A possible explanation could be that from the fifteenth century onwards in Florence and the surrounding area, the Pietra Serena, brought into vogue with the new Renaissance style, becoming the stone material predominantly used both as a construction material and for the production of decorative or architectural elements. The same applies to the bricks, which were widely used as a construction material in buildings in Florence and the countryside from the sixteenth century onwards.

In summary, the historic buildings of Mugello in the first period of construction of religious structures (tenth to twelfth centuries) and the buildings or restorations carried out in subsequent periods strictly depends on the availability of local raw materials. Unfortunately, a study on the historical quarries present in the area is still lacking. The bricks represent a characterizing element that allows connecting the use of a specific raw material with the needs of a client. The hiring of specialized workers probably arises from the significant change in the constructive culture of Mugello, not only for introducing a new building material in architecture but also for the innovations in its production.

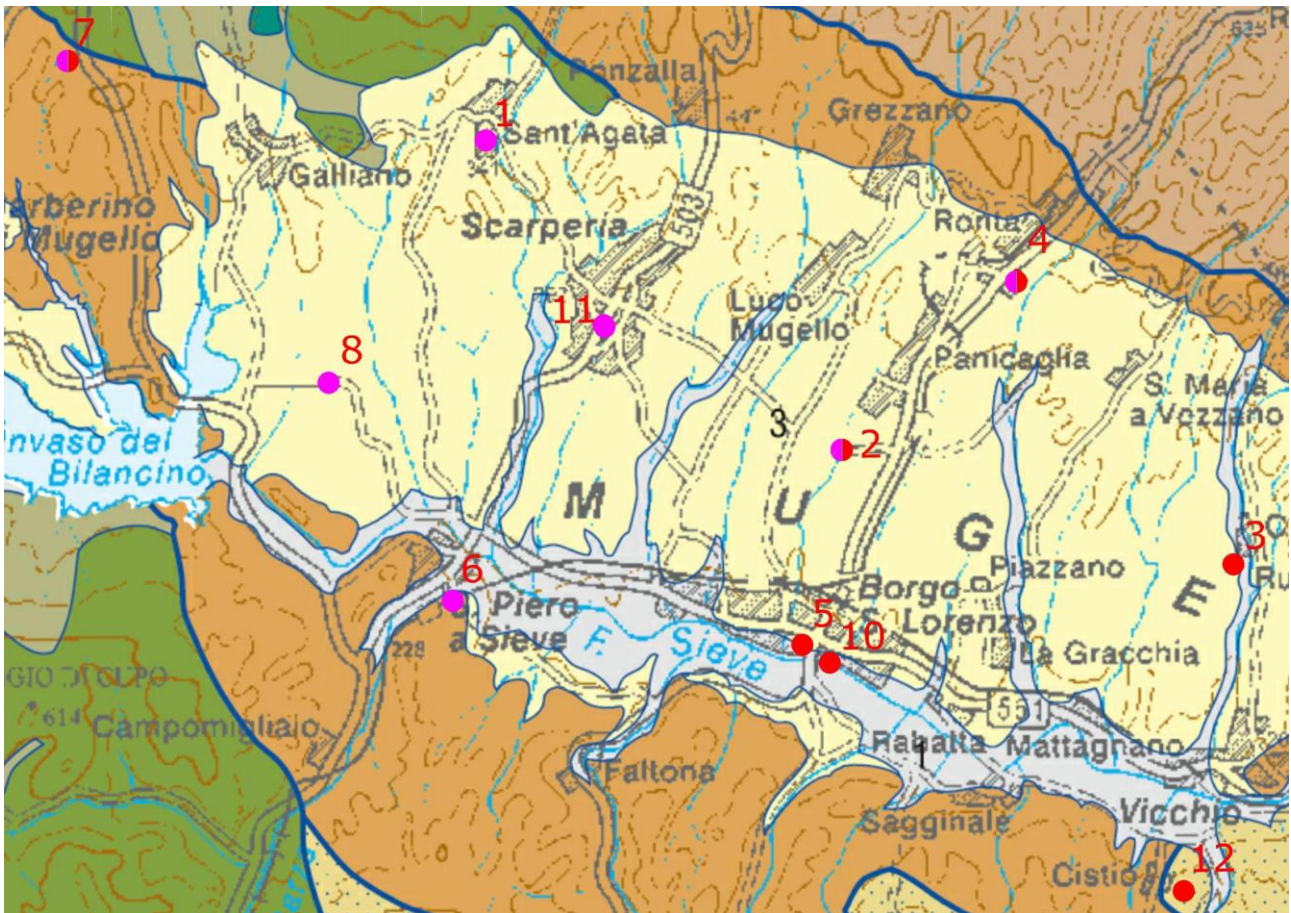


Figure 9 - Building materials used in Mugello in the 16th and early 17th centuries: Pietra Serena (magenta colour) and brick (red colour) (geological map 1:250,000 modified after Carmignani and Lazzarotto 2004).

A chrono-typological atlas of the traditional building techniques of Mugello

By comparing the data obtained from the characterization of the masonries identified in the analysis of the sites, it was possible to propose some considerations regarding the *Wall Construction Techniques* used in the various historical periods, thus allowing the drafting of a "Chrono-Typological Atlas." The first phase of the work involved cataloguing the different techniques, performed by identifying, characterizing, and dating the different masonries in relative chronology using the stratigraphic reading of the architectural artifacts. This operation was followed by comparing the data emerging from the archaeological analyses and the dating proposed by the historical sources. Through this process, it was possible to offer an absolute chronology of five wall techniques. The criteria adopted in the classification of these masonry construction techniques was derived from: Fiorani 1996, and Fiorani 1996b for the processing of materials; Parenti 1987 and Mannoni 2005 for the classification of masonry texture; Bessac 1986 for the finishing of the stone elements.

From the examination of the different Wall Construction Techniques, it is possible to propose the following reflections:

Masonry texture: this seems to be one of the distinctive parameters for understanding the constructive characteristics adopted in Mugello in the different historical periods. *Regular laying* is attested in eight cases, in a chronological span ranging from the 11th to the early 19th century. The laying in *puddled courses*, in regular ashlar made of Pietra Alberese and sandstone (Pietra Serena and Monte Scenario sandstone), and pebbles of Pietra Serena, are attested in four cases, and their use is concentrated from the eleventh to the thirteenth centuries.

The masonry texture worsened in the twentieth century, with irregular laying attested in most cases. Only the monumental buildings located in the city centres (e.g., Pieve di Borgo San Lorenzo) seem to deviate from this phenomenon.

The joints and laying beds seem to be characterized by relatively large dimensional ranges in the 11th century (from 2.2 to 0.5 cm), arriving then at much smaller dimensions in the 12th century (from 1.2 to 0.2cm) and finally to a sort of standardization for constructions of 1420 and 1525-26 (from 0.7 to 0.3cm). From the 18th century onwards, a negative trend is observed that leads to an increase in thickness of the joints, up to total dimensional irregularity for the 20th century. It is also possible to note that Pietra Alberese, when used as the only construction material, is characterized by a joint thickness between 1 and 0.3 cm. In contrast, when used with the limestones and sandstones of the Sillano Formation, it shows joints with dimensions of up to 2.4 cm.

Processing: regarding the processing of the materials concerning the Pietra Alberese, the most representative material among those of the studied buildings, no worsening or improvements are noted in the period examined. There is, in fact, a substantial continuity in the shaping of the ashlars. The heights and widths are rather irregular, except in two cases characterized by extremely standardized sizes. The use of unprocessed Pietra Serena pebbles is observed continuously from the 11th century to the restorations carried out in the 20th century. Finally, in the 20th century, there was an absence of processing of the materials used in the analysed buildings.

Finishing: the surface finishing of the external facing was mainly reconstructed by observing the walls realized in Pietra Alberese, where, thanks to the absence of surface decay, traces of the tools used in the finishing phase remained. The most used tools seem to be those with a flat blade, with continuous use from the twelfth to the nineteenth century. The external flattening of the surfaces is sporadic, observed only in the twelfth and thirteenth centuries walls of the Parish Church of Sant'Agata. The use of the subbia or other pointed instrument is observed only in two cases, one in the twelfth century and the other in the fifteenth century.

Bricks: the dating of the use of bricks in Mugello is unreliable. The measurements were obtained from the analysis of the external and internal masonries of only three Architectural Complexes on Construction Phases dated in absolute or relative chronology.

These data are extremely heterogeneous and let us suppose the presence of non-standardized brick production methods in Mugello. The wide range in the dimensions excludes the possibility of obtaining types of reference from the analysed *Wall Construction Techniques*. For this reason, the data obtained from the brick facings were not used to interpret the evolution of the construction systems in the studied context. On the other hand, the information processed supported the interpretation and dating of the masonry construction techniques in lithic materials, consisting of much more solid databases.

By relating the characteristics of the different analysed techniques, it is possible to propose a "Chrono Typological Atlas of the Mugello Building Techniques," a tool capable of highlighting the manufacturing and laying processes used by the masons in the various historical periods. In this way, it is possible to make assumptions about the constructive characteristics of the buildings in Mugello and the economic-political factors at the base of the choices made by the clients.

The role of local and specialized workers in the construction of buildings

To reconstruct the role of the active subjects in the construction and interventions carried out on the buildings of Mugello in the various historical periods, it is important to integrate the data obtained from the analyses carried out on the construction techniques and the supplying and use of construction materials, with the results emerging from the historical-archaeological analyses carried out on the historical contexts of reference.

The results are divided into chronological periods which concern the main construction periods of the area:

-11th-12th century: for this chronological period, the data on the supplying and use of the main construction materials, the latter mostly derived from raw materials quarried on site, do not seem a criterion that can be used in understanding the choices made by the workers and clients for the construction of buildings. Instead, a distinctive element is the use, albeit sporadic, of materials for specific, decorative purpose available nearby from the place of construction. This is the case of the Monte Calvi Green Marble for the Pieve di Sant'Agata, an element that denotes a very specific will on the part of the clients in choosing the decorative material to be used. The same is for the over-burned vitrified bricks used as a decorative material in the joints of the bell tower of the Pieve di San Giovanni Maggiore. The parameters derived from the analysis of the masonry construction techniques seem to be only partially helpful for the definition of the roles of the subjects involved in the constructions of this historical period. For example, the analysis of the masonries testifies to the diffused good squaring and roughing of ashlar of medium-large dimensions for the realization of regular facings, probably an indication of the presence of specialized workers of local provenance. The ashlar surface finishing is mainly linked to the characteristics of the raw material (sandstone or limestone) rather than to the masons or clients.

-13th century: the main factor that characterizes this construction period seems to be the use of bricks. From a typological point of view, the extremely heterogeneous quality/nature of the brick walls do not allow the proposition of specific categories. However, the use of bricks in historic buildings finds very specific historical and stratigraphic attestations, which lead to the definition of a chronological sequence in its use. In particular, after a first attestation of this material around the middle of the thirteenth century for the rebuilding of the Convent of San Francesco in Borgo, the bricks were used immediately after (the second half of the thirteenth century) in the extensive restorations carried out in the two Franciscan convents present in Mugello (San Francesco a Borgo and Bosco ai Frati) and in the reconstruction of the bell tower of the Pieve di Borgo San Lorenzo. From that moment, the bricks became part of the building materials of the area, arriving in the second half of the sixteenth century to replace the Pietra Alberese. Therefore, the bricks could have been introduced during the thirteenth century for the construction of the convent of San Francesco in Borgo San Lorenzo, built probably with the arrival of Francesco in Mugello (Altieri 2009).

About the workers who produced and realized this brickwork, the morphological similarity between the bell tower of the Pieve di Borgo San Lorenzo (Figs. 10 and 11), built between 1258 and 1263, and the Lombard-style bell towers present in central and Northern Italy could testify the movement of Lombard workers in Mugello in the thirteenth century. The presence of these workers would have led to the consequent introduction of bricks among the construction materials used in the buildings of the area in the 13th century, a phenomenon already widely documented for other areas of Tuscany by numerous published works, which focused on the study of written sources (Salvestrini 2011) and the analysis of material evidence (Bianchi 1996; Frati 2013a, 2013b; Parenti and Quiros Castillo 2000; Pittaluga and Quiros Castillo 1997; Quiros Castillo 1997, 2001).

For this reason, it appears possible that the introduction of this new building material could be related to the arrival of specialized builders from the North and then, given the rapid expansion in its use, become part of the know-how of local workers during the 14th and 15th centuries.



Figure 10 - The bell tower of the Pieve di Borgo San Lorenzo.



Figure 11 - The bell tower of the Pieve di Borgo San Lorenzo.

As for the stone, it is possible to propose precise reflections from the analysed construction techniques. The example that perhaps best testifies to the use of skilled workers in this period is the Pieve di Sant'Agata del Mugello, where the construction material, namely the Pietra Alberese, is put into place through a very well-executed squaring and surface smoothing of the ashlars; such factors could therefore testify to a remarkable ability in the processing of materials by specialized builders, probably hired by wealthy clients. In other cases, such as in the Pieve di San Gavino Adimari, the restoration operations were carried out using local raw materials, roughly hewn, or split and with a laying tending to regularity. Currently, there are no sources which testify to the use of specialized or local workers and the clients who commissioned these works.

-second half of the 16th - early 17th century: intense reconstructions took place following the earthquakes of 1542, 1597, and 1611 (Arrighetti and Minutoli 2019). In this case, the kind of interventions provides a clear overview of the workers and clients involved. For most of the studied buildings, the damage mechanisms activated by earthquakes were not followed by constructive moments of particular importance. On the contrary, only reconstructions aimed at solving individual 'problems' are attested (for example, fracture reconnections and chain insertions, carried out with recycled materials or mixed raw materials, laid down irregularly). Only in one case the written sources (Baccini 1893; Baldi 1878) testify to the intervention of a specific client, represented by the Medici family, which used local specialized workers for the interventions carried out on the Pieve di San Gavino Adimari. In this case, the reconstructions carried out on the church and the bell tower highlight a strong desire on the part of the client to give a new splendour to the building under its patronage. The Pieve di Sant'Agata constitutes a context where intense reconstructions were carried out at the end of the sixteenth century and in the beginning the seventeenth century. This is testified by written sources (Brunori Cianti 2011) and by the stratigraphic reading of the building (Arrighetti 2015),

which point out the presence of two different clients and workers. The first intervention (following the earthquake of 1542) was carried out by the inhabitants of the village of Sant'Agata. They reconnected the cracks and partially rebuilt the church bell tower with recycled materials or mixed raw materials (Fig.12).



Figure 12 - The sketch of the morphology of the bell tower of the Pieve di Sant'Agata del Mugello following the restorations carried out after the earthquake of 1542 by local workers (Brunori Cianti 2011, p.88).

A second construction phase was commissioned by Pievano Nozzolini, who hired local and specialized workers to carry out an actual rebuilding of part of the church and bell tower, using the Pietra Alberese and the Pietra Serena (Fig. 13). In this case, therefore, the interventions carried out following the earthquakes that occurred in 1542 and 1597-1611 differ considerably from each other in terms of the raw materials used and for the processing and finishing of the construction materials. In general, it was the economic resources of the various clients and, consequently, the more or less specialized local workers engaged in the post-earthquake works which influenced the reconstructions carried out in this chronological period.



Figure 13 - The Pieve di Sant'Agata in a photo from 2009.

- *20th century*: The earthquake of 1919 was the main event in this period that led to intense changes in the material structure of the buildings. Following the event, numerous interventions were put in place, ranging from the reconnection of the crack patterns to the complete reconstruction of some buildings damaged by the telluric event. Both written sources and archaeological analysis attest to the evident determination of the central authority to restore certain structures to their splendour, carrying out accurate reconstructions through internal and external transformations of the buildings. This is the case, for example, of the parish church of Borgo San Lorenzo, which was almost totally rebuilt, or the parish churches of San Cassiano in Padule and San Cresci in Valcava, which were demolished to be rebuilt from the foundations (Fig. 14).

Some churches deserve a separate mention which, probably due to their isolated position, lack of funds, or their state of neglect, were only partially restored pending subsequent interventions. Among these are the Pieve di San Gavino Adimari, the Church of Santa Maria a Fabbrica, and the Church of San Bonaventura del Bosco ai Frati.



Figure 14 - The church of San Creci in Valcava, in a photo of 2009, visibly shows its total reconstruction following the earthquake of 1919. The only portion of the building that survived the earthquake is the bell tower.

The study of the bedding mortars of the masonries

The characterization of bedding mortars can have considerable potential in archaeoseismology studies. These materials contain much technological information, starting from the raw materials to arrive at the ‘recipe’ of their realization. Their study contributes to the characterization of the

masonries even when they are realized with the same stone materials and with similar processing and finishing.

The following information will be given on the nature of mortars and why they can provide useful information in archaeoseismology studies.

Mortars are artificial materials produced by man since ancient times and used for various functions, including laying stones and bricks for the realization of the masonries, plastering, pasting tiles, or creating decorations (stucco, etc.). There is also an abundance of mortars with special uses (such as filling holes and sealing).

The mortars are obtained by mixing water and aggregates with a binder, capable of giving the mixture cohesion. It is also possible to add organic additives (such as egg yolk, egg white, casein, animal glue, fig milk, nut oil, linseed oil, blood and resins) natural fibres (for example straw, animal hair and iron filings synthetic fibres and pigments to achieve special characteristics.

The aggregate is added to the mixture to reduce shrinkage and increase the final product's strength. Generally, the aggregate consists of sand from river deposits but can also come from beaches and unconsolidated sand outcrops. The mechanical crushing of rocks can also produce an aggregate.

The following categories can be distinguished among the binders: clay binders, gypsum binders, and lime-based binders. In relation to the latter, the most common in the Italian territory are calcic limes obtained by burning limestones, magnesian limes obtained by burning dolostones, hydraulic limes obtained by burning marly limestones, and limes that have become hydraulic by the addition of particular components.

As for the study of these materials, until the early 1980s, the characterization was mainly based on traditional wet chemical analyses (Jedrzejewska 1960; Cliver 1974; Frizot 1975; Dupas 1981). However, this type of investigation posed problems of interpretation of the analytical data due to the nature of the mortar, consisting of a binder and an aggregate, which are often difficult to separate. Subsequently, it was decided to undertake a mineralogical-petrographic study as if the mortars were a natural compound (rock) (Franchi et al. 1985; Middendorf et al. 2000; Van Balen et al. 2000; Martinet and Quenè 2000; Crisci et al. 2004; Pavia and Caro 2006, Pecchioni et al. 2014).

The petrographic study observes thin sections of the mortar samples under an optical microscope. This allows for the determination of its mineralogical composition, the texture (micritic, microsparitic, sparitic), and structure (homogeneous, lumpy, plague) of the binder and its interaction with the aggregate. It allows the recognition of the presence of materials that give the mixture hydraulicity, such as pozzolana or cocchiopesto. These materials, containing Si and Al compounds in amorphous form, react with lime to form hydrated calcium silicate and hydrated calcium and aluminium silicates, determining a setting even in high humidity or submerged environments.

Regarding the aggregate, the observation of thin sections allows for recognition of the mineralogical and petrographic composition of the aggregate (therefore to identify its origin), the granulometry, and the shape (rounding and sphericity) that allow identifying any selection/sieving, natural origin (sand) or artificial (crushed rocks). The aggregate distribution in the paste can indicate the care taken in mixing the paste itself. Based on the quantity of binder with respect to the aggregate, it is possible to distinguish mixtures with a high binder/aggregate ratio (fat mortars) and mixtures with a low binder/aggregate ratio (lean mortars). Observing the thin section also allows the description of the macroporosity, with the appearance of the pores, the distribution and the percentage by volume, and the description of the additions (such as straw), if present. Regarding the raw materials used in the realization of a mortar, this type of study allows information on the supply areas. Different raw materials can be linked to the different construction phases.

In the context of Mugello archaeoseismology, the first application of the petrographic study of the bedding mortars was made on the parish church of Sant'Agata as part of an international project entitled *AcRoSs - Archaeoseismology, Restoration, Seismology*. The project involved an interdisciplinary group with researchers from two nations (Italy-France). Between 2018-19, the team developed an innovative research project for the analysis of the building based on the creation of a digital model of the church and the annexed buildings through the integration of products. These

products were derived from the use of modern technologies, the design of which integrated historical-archaeological analyses, the three-dimensional survey of the structure with the aid of laser scanners, terrestrial and drone photogrammetry, analyses on construction materials with particular reference to mortars and stone and brick elements, and a series of information obtained through the auscultation of the response building to seismic noise. The results have not yet been published, but a personal communication from the authors confirmed the usefulness of the data provided, especially in differentiating construction phases otherwise not easily recognizable on a macroscopic basis. Other studies of bedding mortars in this area of Tuscany, not connected, however, to studies of archaeosismology, concern the sixteenth century Medici Fortress of San Piero a Sieve and the tower of the Trebbio Castle (15th-16th century). About the Fortress, the mortars are characterized by very fatty mixtures (binder/aggregate ratio varying from 1/1 to 1/2) and a fine aggregate of unimodal granulometry (Fig. 15).

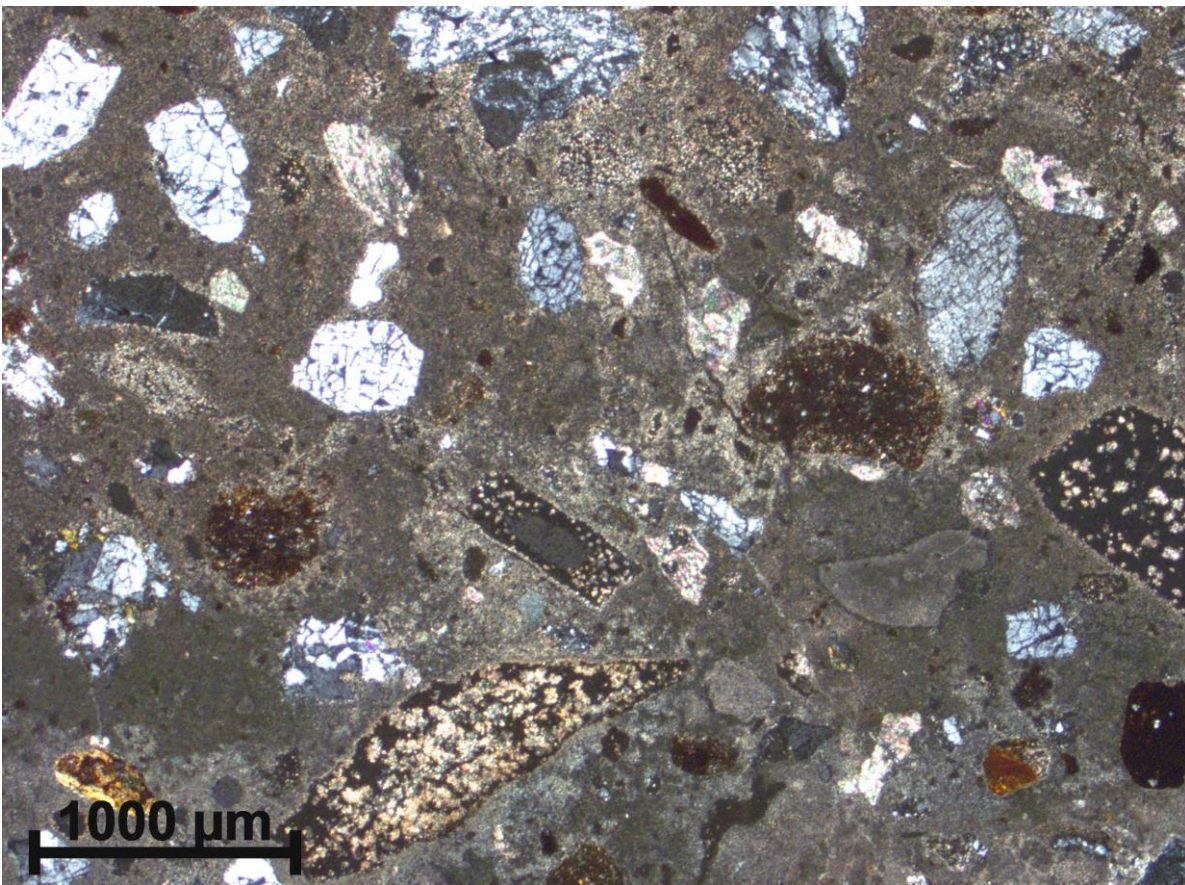


Figure 15 - Thin section in polarized transmitted light. It is possible to see the abundant binder and the unimodal grain size aggregate consisting of single crystals of quartz and feldspar.

Regarding the binder, the presence of burnt remains of Pietra Alberese indicates this limestone is the raw material for the production of lime (Fig. 16) (Fratini et al. 2018). The exceptional mechanical characteristics of these mortars would suggest the possible selection of a variety of Pietra Alberese richer in clay, capable of providing a high hydraulicity (Fratini et al. 1994). The widespread recrystallization phenomena suffered by the binder must also be considered to justify the performances of these mortars (Fig. 17). Overall, for their petrographic aspect and effective binding properties, these mortars are comparable with those present in Brunelleschi's Dome of the Cathedral of Santa Maria del Fiore in Florence (Barbi, 1986; Pecchioni 2012). Different types of mixtures have been identified for the mortars taken from Castello del Trebbio, which are distinguished by the amount of binder (Figs. 18 and 19) (unpublished data).



Figure 16 - Thin section in polarized transmitted light. Underburnt fragment of Pietra Alberese indicating that this limestone was the raw material for the production of lime.

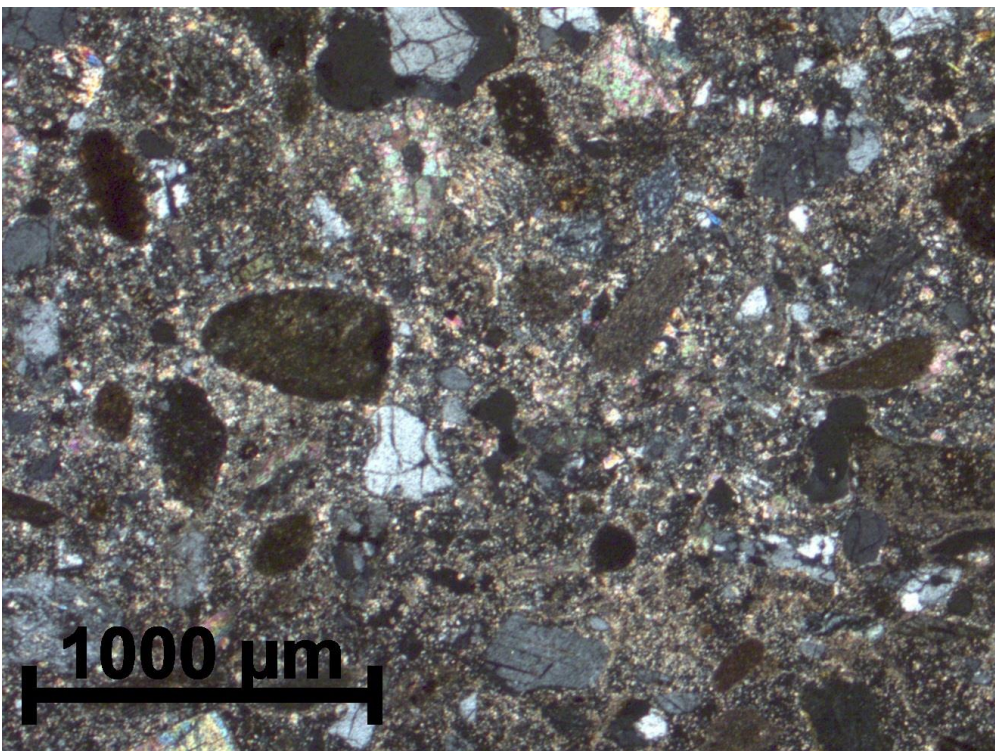


Figure 17 - Thin section in polarized transmitted light. The strong recrystallization of the lime binder is evident.

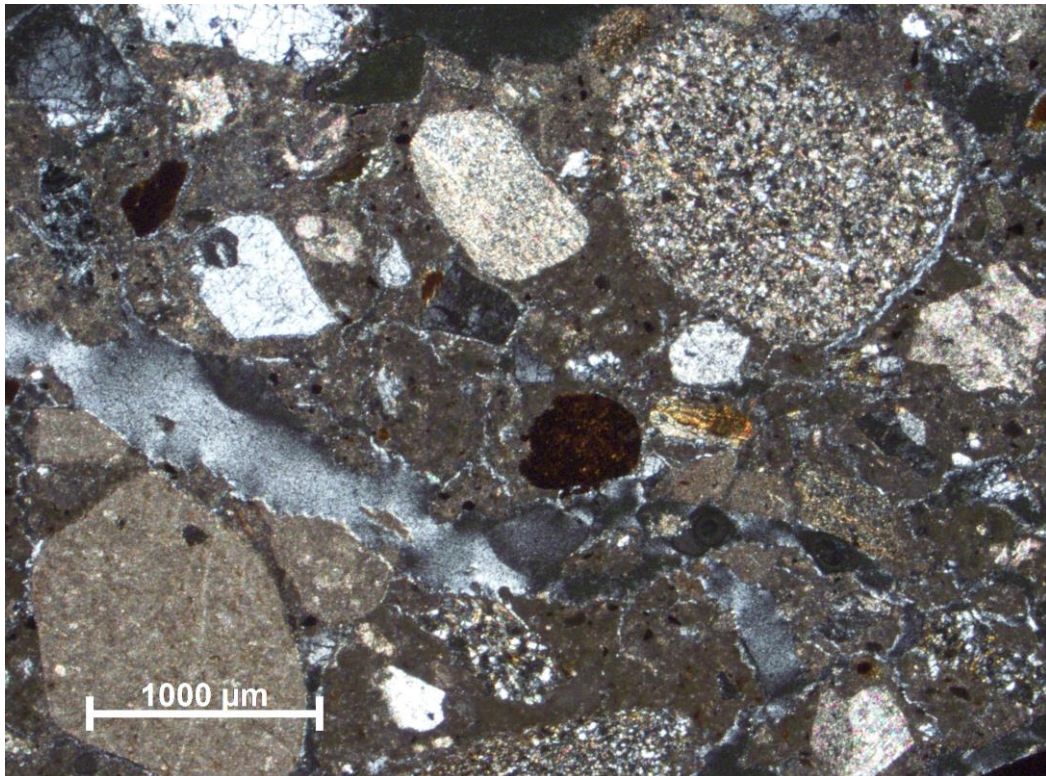


Figure 18 - Thin section in polarized transmitted light. It is possible to see the aggregate of bimodal grain size consisting of arenaceous fand limestone fragments, single crystals of quartz, feldspar, and sparitic calcite (Castello del Trebbio).

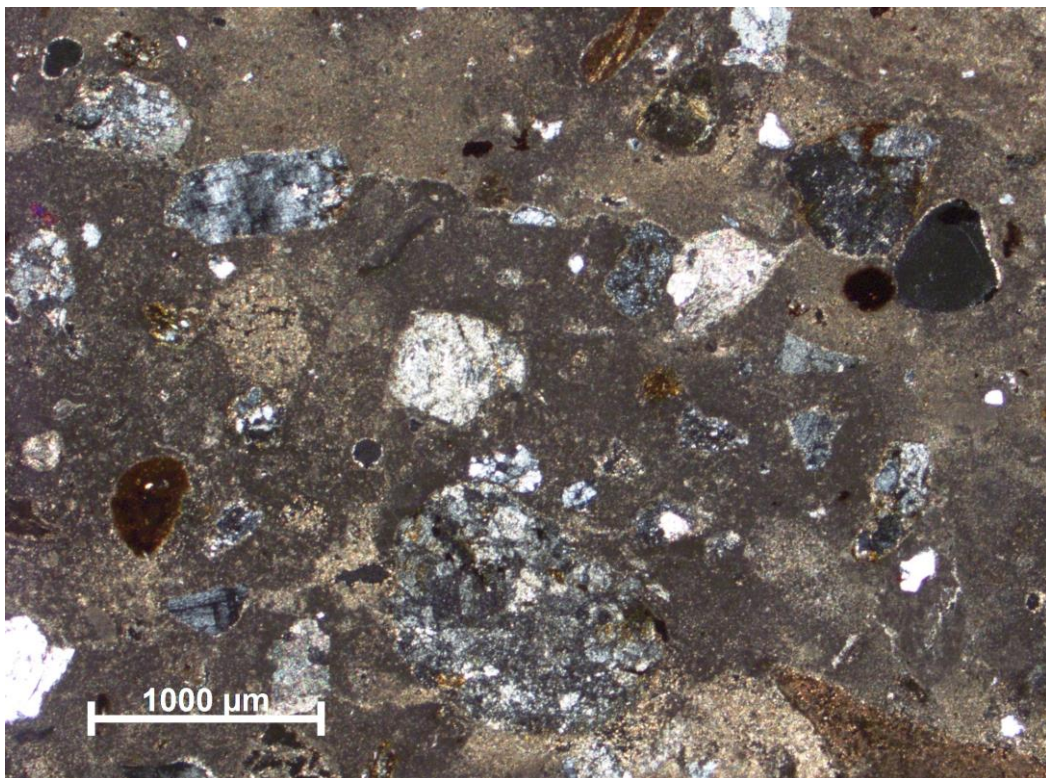


Figure 19 - Thin section in polarized transmitted light. It is possible to see the abundant binder and the unimodal grain size aggregate consisting of single crystals of quartz, feldspar, and sparitic calcite, arenaceous fragments, and rare cocchiopesto (Castello del Trebbio).

Conclusions

Clients, workers, and raw materials are the three elements that form the basis of the main choices made in Mugello in the various historical periods for buildings and interventions of different types (from restorations to reconstructions). The results that emerged from the research indicate that these factors influenced the construction of buildings in a certain place and in a certain historical period. Mostly of religious origin, the clients have often resorted to specialized workers, probably already present and operating in the area in the aforementioned historical periods. Instead, the use of non-native workers seems to be documented around the middle of the thirteenth century for the sole construction of the Pieve di Borgo San Lorenzo bell tower, where the building model shows architectural characteristics related to the Lombard style. The use of raw materials seems to be linked to purely technical and practical factors. The availability and exploitation of outcrops of specific construction materials and the introduction of more promising building technology (the introduction of brick which along the three centuries replaces the Pietra Alberese) guided the choices made by clients and workers in the analysed periods.

Post-seismic interventions deserve a separate discussion, where a sort of differentiation seems to emerge. In the sixteenth century, the buildings testify to a double reality: the hasty restorations carried out a few days after a given seismic event, made by the inhabitants themselves to solve the most evident damage caused by the earthquake (such as cracks reconstructions and partial reconstruction of roofs) with rather approximate construction techniques, and more specialized interventions carried out even a century after the events and linked to the requests of specific clients (such as the Medici family and some parish priests). In this second case, the accuracy in the construction materials' selection, processing, and equipment denotes the presence of specialized workers who were probably local residents. In the twentieth century, the situation changed again: following the earthquake of 1919, the most prestigious buildings in city centres underwent major restorations while the isolated architectural complexes remained abandoned or made safe through temporary measures which became definitive, making them vulnerable to structural hazards.

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