The catalogue of earthen mortar walls in Cremona in order to evaluate their mechanical behaviour: the complexity and logic behind a construction technique

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ABSTRACT: In Northern Italy even in aristocratic residences and religious buildings earthen mortars are commonly used. Their composition and their execution are complex, however earthen mortar brick walls are of excellent quality. In Cremona earthen mortars have been widely used from the Middle Ages to the first half of the Eighteenth century. The thickness of the walls is considerable, at least four heads of bricks, their tissue is regular from the front to the back of the wall. Their resistance to compression has shown results similar to those of walls of the same period constructed with lime based mortar. From the Sixteenth century onwards beyond the vaulted ceiling of cellars, above ground, often appear real and elaborate vaults which are not necessarily constructed with lime mortar. A catalogue which also deals with different forms of deterioration and decay, is nonetheless useful to define the real building characteristics of these walls and their interaction with other structures in the buildings.

Keywords: *earthen mortars, Cremona, vaults*

1 INTRODUCTION

Brick walls, built using earthen mortar, are widespread in Europe starting from the “classical” period [1]. Often, however and particularly in rural areas, it is a poor “mixed” masonry, in which cobblestones or stone chips are used [2]. The use of earthen mortars appears to be linked to the analogous experience of construction either entirely using earth (in its various techniques) or a wooden-frame with earth based infill, typically clay, either with or without a some fibrous re-enforcing material (straw, hay, etc). In Northern Italy we find carefully constructed brick masonry walls, built using earthen mortar: these examples, starting from the Middle Ages, co-exist alongside walls built with lime and continued until the middle of the Nineteenth century, when the industrial production of lime mortars gradually led to the dying out of the use of earthen mortar as being an outdated technique.

Nonetheless, as early as the Sixteenth century Pellegrino Tibaldi [3] raised doubts about its performance: “... no where is there a quarry to make good sand, sometimes not even in the rivers [...] in Milan, because of the scarcity of sand, the earth excavated for the building construction is used with clayey soil, otherwise used for cultivation: these materials are mixed with lime with which they combine well. These walls are, however, weak...”. The painter and architect Tibaldi not only confirms the custom of using the Lombard sand recovered from the excavation for foundations (an obvious

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policy in a flood plain), but highlights a feature of this mortar, i.e. the mixture of sandy silt or clay (to which has been intentionally added sand) and lime; a practice which is reported from the Roman period [4] and which seems to differentiate these walls from the poorer ones that appear elsewhere (especially in the countryside) [5]. In Cremona, the mixture of clay, sand and lime (quicklime probably), was called “bazzana”[6], that means “mixed“, and was used almost exclusively in buildings of great importance and of highly detailed execution (Figure 1): including important Sixteenth century buildings which are evidence of the wealth of a city that, with its 35,000 inhabitants in the Sixteenth century [7], was one of a group of medium-to-large-sized centres in the Po valley and had a political and economic weight, much greater than its current one. It was not, however, an “obligatory” choice: excellent lime was available at prices which (for the period) were not particularly onerous: a lime which was high in calcium was available from pebbles taken from the nearby river Adda, while hydraulic lime (Piacenza lime) was available from the Trebbia river, both being transported via the Po river.

Figure 1. Detail of an earthen mortar masonry and the dripping of the earthen mortar, palazzo Magio Grasselli.

The first studies were published in Cremona, and further investigations are in progress: initial results are presented with appropriate references by Maria Pia Riccardi *et alii* [8]. Archaeological excavations have yielded remains of rich residences (of the Roman period), with paintings and mosaics, using the technique *opus craticium*, with wooden structure infilled with clay [9]. The use of *fachwerk* construction is confirmed until the Fourteenth century, when houses were gradually rebuilt with brick walls, as highlighted in the citizens Statutes of 1388 which established the obligation for holders of political office to build a house of brick with a tiled roof [10]. The combination of masonry earth mortars with brick walls then links Cremona with a pre-existing tradition in the use of these materials.

Dominating the houses, which were mostly wooden (or *fachwerk*) were the Cathedral, the “Torrazzo”, the Baptistery and the Palazzo Comunale [11] as well as other large brick built constructions of the Twelfth or Thirteenth century; these buildings, exceptional both for their size and social importance have very regular, thin lime mortar joints. On the contrary housing – including monasteries - from the Late Middle Ages (Fourteenth-Fifteenth centuries) to the Fourteenth century made use of “bazzana” in various forms. During the Fifteenth century two practices both of which were ancient began to mix methods: one precise and refined of the most famous building sites and the second using more perishable materials for more modest timber-framed buildings. Perhaps the demand (the reconstruction of an entire city in brick) during an economic boom, may have encouraged the use of clay, readily available and proven over a period of more than a thousand years, also as a mortar. The modest two or three storey homes, which rarely exceed three metres per floor and which include ground floor workshops, that form the prospect of the road – whilst having structural traits in common – can hardly be claimed to share a homogeneous structural model: the combination of continuous modifications, systematic reuse and maintenance have profoundly transformed these buildings leaving unchanged only the “spine” walls that, rather than separating the properties, tend to aggregate them into more complex buildings. Conversely the more affluent homes, usually with only two floors above ground, and the great houses of the nobility that extend to incorporate neighbouring properties, have similar structural features which, though each has its own particular construction and maintenance history, can nonetheless be compared. A good bibliography [12] and a systematic survey of the vast property stock owned by the Municipality, which includes many of these buildings, allow us to compare a large number of cases. In about fifty cases, good quality metric survey and documentary research are available on the deterioration at different levels of detail. In four cases (palazzo Pallavicino Ariguzzi, palazzo Pallavicino Soldi, palazzo Raimondi, palazzo Magio Grasselli) the documentation is both homogeneous and extensive and also includes materials, testing and a systematic series of thermographic images. Within this housing stock, it is possible to recognize and analyse in detail structural elements, structural shapes and forms of static deterioration recurrent in an area much larger than the region around Cremona.

2 EARTHEN MORTAR WALL: ITS GEOMETRICAL FEATURES AND DECAY

The walls are laid in regular courses throughout their thickness. Their depth coincides generally with multiples of a “head” of brick, typically four or five heads. A wall of four heads has the depth of a ”braccio” (a Cremonese measure being about 0,483 meters), and its corresponding cubic volume, the “quadretto”, contains thirty-four bricks, while the outer surface of a ”braccio” to the side, contains ten: this information is reported by Alessandro Capra, an architect who worked in Cremona in the Seventeenth century [13]; in his writings (technical manuals with various titles but largely identical content, essentially revised subsequent editions) he gives a faithful, though not exhaustive, portrait of the Cremonese building site of the Modern Age [14]. He details, in particular, the recommended ways in which to build the walls often found in buildings of the period. He recommends using whole bricks, avoiding breaking them, and to make the joints (the laying beds) as thin – that is slightly more than a centimetre – and evenly as possible, therefore significantly higher than those of the churches and civic buildings of the Thirteenth-Fourteenth centuries. On the walls – which until the Sixteenth century were left exposed – horizontal joints are to be of great regularity, while vertical ones should be arranged irregularly due to the slight differences in thickness of the joints themselves and the variations in the bricks (generally around thirty centimetres long) which occurred during baking [15].

The regularity of the construction (and therefore the even distribution of the load) helped limit the thickness of the wall. Its regular construction, excluding any form of filling conglomerate composed of fragments, led Capra to warn that it was inadvisable to employ two separate teams of workers starting at opposite ends of a wall, since it would be virtually impossible to rectify the minor faults caused by the different styles and working methods of the two teams of labourers. The pointing and finishing of the external surface are an essential contribution to the strength and duration, and are so systematic and durable that even today it is difficult, when there are no openings in breakage or other damage, to recognize the clay mortar. The joints are filled with high calcium lime mortar which has often been pressed using a metal instrument. The covering in lime slows changes in temperature and humidity preventing the progressive powdering of clay mortar that is alternately wet and dry. The washing away of the clay joints can lead to forms of deterioration (Figure 2) and serious collapse. The analysis of the environmental parameters of Cremona has shown that, for most of the winter season, the relative humidity stands at 100% [16], with an appreciable effect on the conservation of buildings: the absorption of moisture and the effects of water run-off on the external face, such as rain, results in the erosion of the joints. The covering also provides protection from other deteriorative phenomena: the walls with exposed earthen joints are frequently subject to be attacked by insects – these nest in the interstices and in some cases dig deep tunnels – and weeds.

Figure 2. Decay of earthen mortars in palazzo Magio Grasselli

An interesting series of earthen mortars and their related forms of deterioration is visible in palazzo Magio Grasselli [17], whose Seventeenth-century restructuring assembled into a single building a number of pre-existing constructions, of which there are still traces in the walls: the deterioration of the plaster of the main façade has left visible the different textures of the walls that made up the pre-existing buildings, all built with clay mortar. A Fifteenth-century house incorporated in the palace, the so-called “Casa Lotica” on the western side of the façade, presents very regular horizontal brick courses, with vertical staggered joints and intact bricks. The clay mortar is protected from atmospheric agents and moisture condensation thanks to a lime based joint covering with traces of “fregatura” – a protective finish of the exposed brick – and a red tint, used to make the hue of the facing brick uniform. Only in the Seventeenth century, was this surface covered with a clay and lime plaster of which only fragments remain.

The use of earthen mortar for chimneys or discontinuities in the walls such as openings, windows or building joints has resulted, in many cases, in the appearance of clay dripping along the masonry. Diagnostic tests performed on masonry – both protected with plaster and bare – show substantial differences in the tension value at collapse, respectively 1.97 and 1.10 MPa (Figure 3; Table 1), and elasticity, which decreases rapidly with the increase of pressure applied. In both tests the jack plate penetrates no more than half of the thickness of the wall sections, and the values should be reconsidered taking into consideration the entire thickness. The values obtained would be far closer if you were to consider the entire depth of the wall; the shallow joints which (now empty due to the deterioration of the masonry) also contribute to the difference.

Figure 3. Tests with jack plates in earthen mortar masonries, palazzo Pallavicino Ariguzzi, April 1992.Two masonries with analogous building characteristics, but in different state of preservation, have been examined to determine their structural behaviour.

In the more severely damaged masonry, we find a greater use of brick fragments, identifiable by a sequence composed mainly of bricks of the head.Even the thickness of the joints, a little over one centimeter in the walls face, is irregular – often exceeding 2 cm – to obviate the different heights of the fragments. Such fragments can also show damage on the visible brick facing, and the plaster which covers the entire wall fills the cavities. To accomplish this layer, increasingly popular since the Sixteenth century, not only because it allows you to reuse fragments, but to incorporate more or less extensive portions of pre-existing buildings, radically transforming them, the options are numerous: entirely lime mortar, filling the gaps in the joints, overlapping the clay with a thinner layer of plaster, or even a layer of very compact clay plaster that in turn is protected by a layer of lime based paint.

Table 1. Stress-strain values, brick masonry with earthen mortars, palace Pallavicino Ariguzzi (Cremona), April 1992. Tests with double iack plates report the values of two masonries, one deteriorated (test n.1), the other in good state of preservation (test n.2).

Test no.	Stress State	Tension Value at Collapse	Elastic Modulus	Δ_p
1	0,25	1,10	923	0,2-0,4 MPa
			747	0,4-0,6 MPa
			290	0,6-0,8 MPa
2	0,38	1,97	596	0,2-0,4 MPa
			504	0,4-0,6 MPa
			820	0,6-0,8 MPa

While the joints, confined to the cavity between the bricks, have generally resisted the passage of time well, plasters appear more frequently detached, even when (following a common usage that extended until the early Twentieth century) they are very thin; as can be seen on the façades of palazzo Pallavicini Ariguzzi [18], these thin coats survived better than the heavy hydraulic lime plaster of the late Nineteenth century. The causes and specific modes of decay - especially detaching - remain to be studied, but almost certainly they involve various physical phenomena (water flow, thermal insulation of walls and its variations etc.) as well as chemical reactions. These considerations also apply to the bedding mortar, and therefore to the walls as a whole.

The height of the interior and that of the prospect onto the road are often notable. The “interfloor” ranges from ten to fourteen cremonese “braccio”, measured from the floor to the ceiling above. The façades can exceed fifteen metres to the gutter line. The “spine” walls and the wooden floors, in attics and between the ground and first floor (where the ceiling may be replaced with vaults) contrast the relative slenderness of the dividing walls. The prevalence of continuous walls, with few openings, seems to reduce the vulnerability. The projection of the narrow masonry pier, which is flanked by two windows, in the wing of the Seventeenth century palazzo Pallavicini Ariguzzi, was probably caused when in addition to the thrust of the two overlapping groin vaults – built at the time of construction – was added, after the restoration of 1964, that of the roof. The cracks in the arches of the windows of the living room on the courtyard of the palazzo Magio – which are also separated by brick masonries – highlight the discontinuity related to work performed in the late Eighteenth century to change the windows below, adapting them to match those of the mezzanines. The foundations are laid on a layer of well compacted clay, sand, silt and brick fragments. Although Capra recommends a cross section greater than that of the overlying wall (Figure 4), projecting equally on both sides, it is the walls of the cellars – which do not vary in thickness – that transfer the load to the ground up to fifty-sixty centimetres below the floor level: this base connected by heavy vaults stabilizes and connects the various elements of the overall structure.

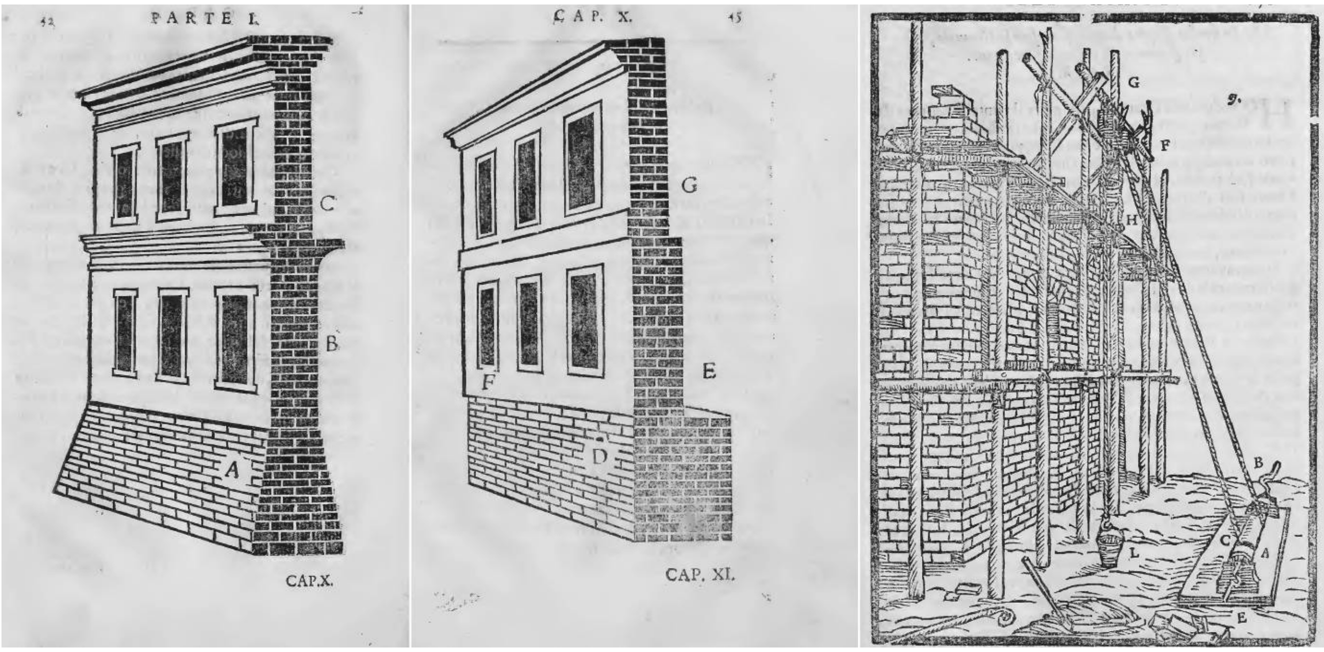

Figure 4. In Cremona earthen mortar walls are generally laid in regular courses of bricks throughout all their thickness. Alessandro Capra, *Geometria famigliare, et instruttione pratica* … (1671).

Often even the vaults are constructed in earthen mortar: thereby eliminating the problem of the withdrawal of the vaults when they are dismantled, even if sandy soil was used as centering. Intuitively, the builders of the Middle Ages and the Modern Age, realized that brick masonry earthen mortar resists compression; so in the early Nineteenth century Domenico Voghera, admired building entrepreneur and father of the more famous Luigi, built in “good bazzana” the bell tower of San Martino al Lago [20]. While “bazzana”, especially if it is well compressed hardens and is not easy to detach, for example, fragments of plaster, but it has poor tensile strenght. Therefore, some elements of the masonry such as arches, lintels, cornices and parapets of a single head below the windows are usually performed in lime, as well as most patches and liners, i.e. those parts that need to be anchored to the wall mass. Still regarding palazzo Magio Grasselli, where the masonry of the originally adjoined Fifteenth-century house shows a discontinuity in the facing bricks between the ground and the first floor: it is a cornice chiselled to match the plane of the façade. This frame was made of bricks of dimensions even more regular, with a mixture much more compact, probably shaped from the outset with friezes or projecting mouldings. The bricks are joined by thin mortar joints of only lime and the construction technique is different to that of the surrounding masonry, in clay mortar; this fact is explained by the fragility of the projecting frame which is therefore exposed to atmospheric agents. The precision in the laying of bricks and in the thickness of the joints did not provide further structural performance but rather a correct installation of the moulded tiles in a frieze spanning more than ten meters. In the more common and later cases, if the mouldings do not protrude more than the length of a brick, you can lay successive layers – of an appropriate thickness – composed of variously shaped bricks, balancing the load on both sides, in order to very gradually increase the section, always using earthen mortar. The drawings of Alessandro Capra are very clear in this regard.

Complex structures, very different one from the other are the rare vaulted eaves, sometimes lunettes, dating from the late Fifteenth and early Sixteenth century. In the later more common cases, if the mouldings do not protrude more than the length of a brick, the effect is achieved by adding successive layers of a suitable thickness (Figure 5), balancing the loads on both sides in order to increase very gradually the section, always using earthen mortar. However it is preferable, to construct the projection with corbels, more than half a meter high, either volute or cyma reversa, in brick knitted into the body of the wall using lime mortar and then plastered. Above the corbels protrude further variously shaped joists. These and the boards that connect them are of wood. Returning to palazzo Magio Grasselli, in the Seventeenth-century a cornice was built on the façade towards the street. A portion of the corbels, which are breaking away is executed in lime mortar, but on others can be found fragments of plaster and some backfill in clay. The substitution of the woodwork with similar elements in stone in 1877 leads to a doubt. The replacement of these lightweight structures with stone elements in the Nineteenth century required a number of repairs, in particular when the roof joists were not attached to a transversal wooden beam, resulting in a growing pressure on the wall of the façade, free beyond the level of the ceiling of the top floor.

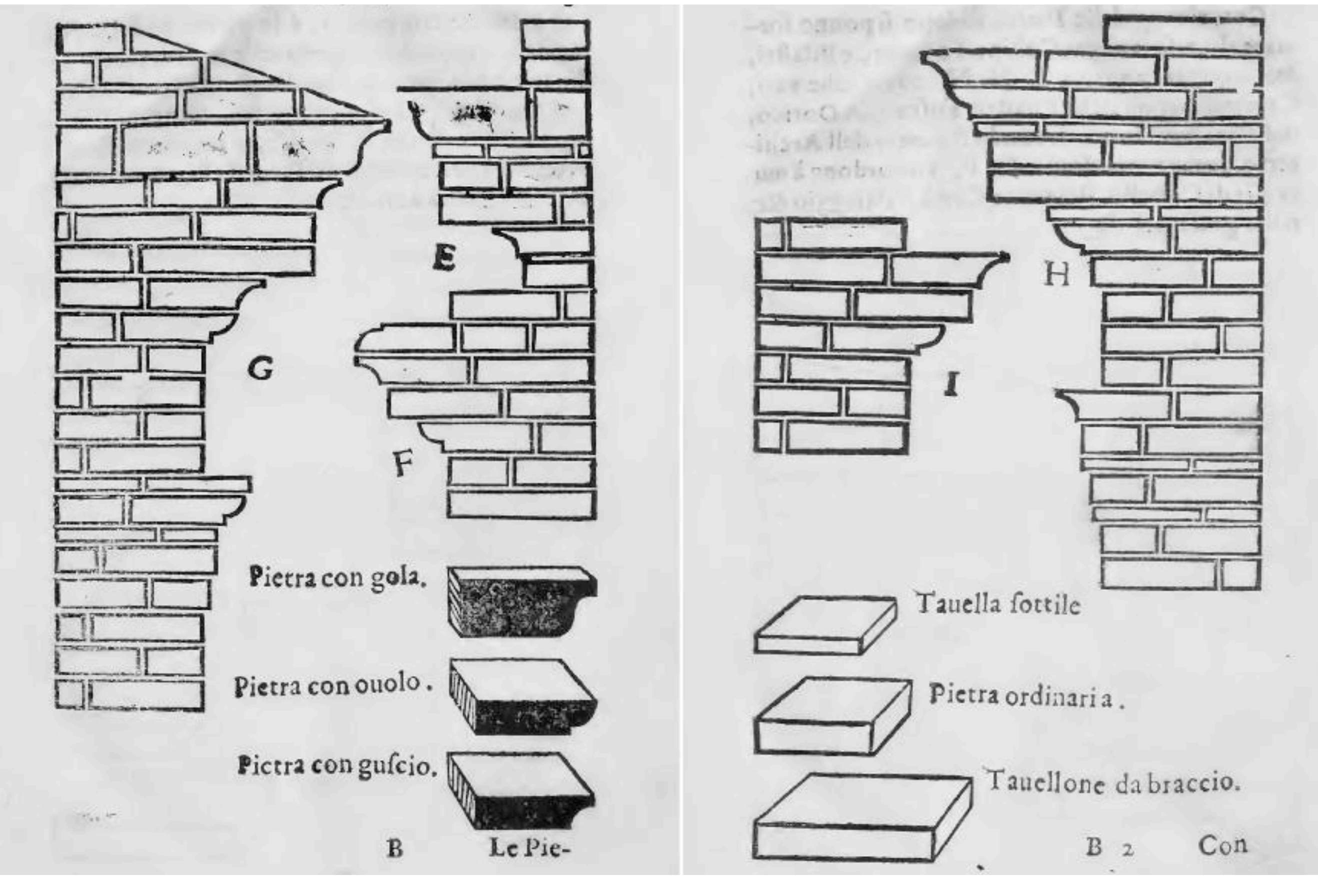

Figure 5. In case of slight eaves overhang, brick and clay mortar walls are used, in spite of their low resistance to shear stress. Alessandro Capra, *Geometria famigliare, et instruttione pratica* … (1671), pp. 9 and 11.

3 VAULTS BUILT ON EARTHEN MORTAR WALLS

In some respects the vaults have a similar impact to that of the eaves: from the Fifteenth century they have progressively replaced the wooden ceilings of the ground floor. In monastic buildings, from the “Corpus Domini” monastery to the monumental “Casa degli Umiliati in Sant'Abbondio”, they are part of the original construction; however in civil buildings they are, more often, later additions to existing walls. For floors above ground, they are almost exclusively constructed with lime mortar. Barrel, groined cloister or umbrella vaults of the Fifteenth century, with sequences of corbels and small arches, were followed in the Sixteenth century by cloister vaults with larger groins and corbels similar size of the arches, realized in a herringbone pattern. Both springers and corbels are strongly inclined to reduce the drift transmitted by the bricks that are set to not more than one head in the masonry, while the arch is often simply placed against the wall. When it is necessary a continuous springer, the procedure used for the frames of the gutter is often replicated: this is achieved by progressively increasing the jutting out of rows of bricks bonded by earthen mortars. In both cases, on the springers of the vaults, bricks are laid *in folio* so as to reduce the weight. A combination of thicker and steeply inclined springers and an almost flat surface can be seen in the vaults of two rooms on the first floor of the palazzo Ariguzzi Pallavicino, in a wing added around 1671 (Figure 6). The springers of the vaults are built with a single brick course, laid horizontally, in continuity with the vertical walls. These continue for almost half of the height of the vault and allow the formation of the sweep.

Figure 6. Detail of a vault in palazzo Pallavicino Ariguzzi.

The variant of palazzo Magio Grasselli looks rather like a cloister vault with a polycentric curvilinear profile on its lower surface: the profile, unusual even when compared to other vaults in the palace, is characterized by the distinctly vertical slope of the four coves and summit (corresponding to the central medallion) which is substantially flat. Bricks are laid edgewise, diagonal to the plane of the springers which in this case are at each corner to form a series of arcs of different radius, adapted to the irregularity of the room, the corners are not visible, the surface being continuous would allow the decoration to be independent of the articulation of the vault. The bricks of the four coves and those employed to build the central medallion are the same size 30×13.5×8.5 cm, and were sufficiently sturdy as effectively to withstand shear stress. The architect Francesco Pescaroli did not use iron rod thrust–ties for balancing the thrust, but constructed two stiffening ribs, turned toward the wall to the kitchen court (which lacked the contrast offered by the front and by the internal wall of the gallery). Unlike the walls, made of clay bricks and mortar, the joints between the bricks of the vault are laid exclusively with lime mortar. Alternatively, the bricks are laid edgewise: an example of the vault can be found in Palazzo Raimondi [21], built in the last decade of the Fifteenth century by the noble Eliseo Raimondi, amateur architecture, aided by the architect Bernardino de Lera and the sculptor Gaspare Pedone from Lugano. The building which is celebrated for its Renaissance façade in Botticino and Rosso Veronese stones, has undergone substantial changes. While very little remains of the Fifteenth century wooden floors, the vertical walls of earthen mortar are however almost entirely preserved. The type and construction technique of the large vaults on the ground floor suggest a Seventeenth century reworking. Some show a texture similar to that of palazzo Pallavicino Ariguzzi, with the first courses of brick laid horizontally – in continuity with the courses of the perimeter walls – which rest on inclined courses laid in a herringbone pattern. This technique distributes the load of the vault more uniformly onto the walls below, limiting overloading and concentrated horizontal thrusts: recent thermographic imaging have verified the precision of the walls construction and the correspondence of instances of instability with later ill-considered modifications (Figure 7). The reduction of the horizontal thrust is essentially entrusted to the type of laying bricks and their form. Chains occur only rarely, when they do, they are extrados and simply connect the opposing walls, without any specific relationship to the geometry of the individual vaults and not always consistent with the location of the stiffening ribs above the vault.

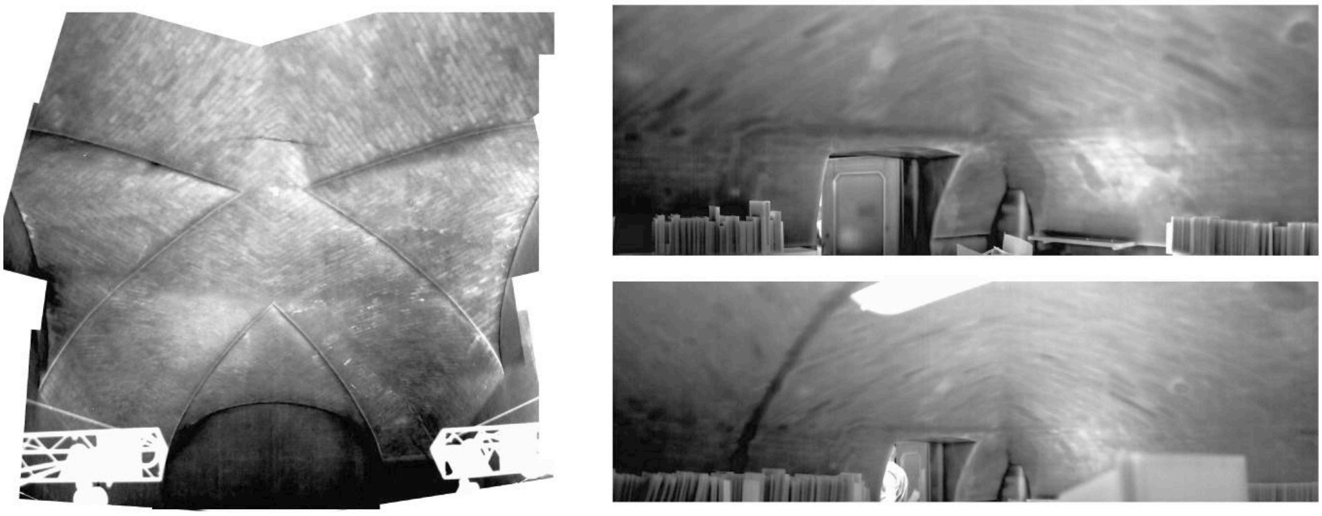

Figure 7. Thermographic view of some vaults in palazzo Raimondi, June 2013.

In Cremona, the system of stiffening ribs is followed by "arched" vaults, in use from the end of the Sixteenth century: like the corbels of the groined vaults, these vaults put less strain on the walls, and allow to divide the space into a sequence of smaller vaults, often built *in folio*. A late example of such vaults can be found in palazzo Roncadelli-Manna, where in the Seventeenth century architect Francesco Pescaroli began major reform of the existing buildings [22].

Until the early Eighteenth century vaults were found primarily on ground floors, while in the Eighteenth century and the first half of the Nineteenth these are also used for the large rooms of the piano nobile: they are light vaults, whose upper surface is exposed, because the attics above them were no longer needed to preserve foodstuffs. They therefore built vaults on the first floor leaving the existing ceilings unchanged on the ground floor, especially when such rooms were used for administration or as service rooms. The inner wings of the palazzo Cattaneo and palazzo Magio Grasselli, despite being "new" constructions, had vaults in the cellars and piano nobile while ceilings, rather hastily finished, were constructed on the ground floor. In the Seventeenth century the use of extrados reinforcing chains and of carefully constructed stiffening ribs – placed in a more coherent and effective manner – is widespread and systematic, and gradually the parabolic arcs of the vaults become lower and flatter. It is well known that these "light" vaults are damaged primarily by changes to their geometry, following the failure of springers or the projection of the walls on which they rest. The presence of wooden chains along the entire perimeter of the cloister vaults serves precisely to provide additional resistance to deformation.

The cracks due to changes and joints in the construction can, in the right conditions, easily increased. In palazzo Pallavicino Soldi, formerly the residence of the families Affaitati and Pallavicino of Busseto, the complex pattern of cracks, seen in the space housing, the staircase is not due to deformation of the walls built using earthern mortars, but to extrinsic factors. The south wall of this room built with earthern mortar, is composed of a number of different "textures", being originally a dividing wall of two properties, on which the floors and vaults (on both sides) rested. The complete demolition of the adjoined building in the first half of the Nineteenth century [23] – to achieve the expansion of the neighbouring hospital, designed by architect Carlo Visioli - had the effect of creating an imbalance in the structure, now loaded on only one side and free on the other for its entire height of over 15 metres. Although the wall has been anchored at the summit, where the garrets are located, spontaneous cracks have appeared along the masonry and in the vault above the staircase. What's more the earthquake that affected the city in 1951 had the effect of increasing the existing cracks: the vault of the staircase, the lintels of the internal doors and some walls had cracks which were therefore repaired. Although the city has been widely built with earthern mortar, the earthquake did not cause significant damage, but rather resulted in a number of small cracks, in particular in buildings where ill considered changes had been made in the construction. The resistance of the material leads to some reflections on the effective shear strength of masonry earthern mortar: the recent earthquake in Mantova, where "bazzana" is still widespread, has allowed us to verify a certain resistance to the collapse of the walls, as it was observed during the demolition of the bell tower of the church of Bondanello in Moglia. The analysis of the masonry work has shown how the calcium lime component has migrated towards the surface of contact with the bricks to form a very thin and compact layer, which is very well bonded to the brick. The origin and the effects of this concretion on the performance of the masonry are being verified.

So a good conservation of the walls (and consequently of the vaults) presupposes that stresses, even temporary, that can affect the poor tensile strength of the mortar, are to be avoided. An example is offered by palazzo Raimondi, where the lowering of the floor of a basement and the subsequent execution of underpinning, caused evident cracks in the arches of the windows (which had already been changed in the Nineteenth century) and in the vaults of the two floors above ground, respectively, of the Seventeenth and the Nineteenth century. The repair of the masonry, with earthen mortars, can not be achieved with similar existing material. Although the adhesion between brick, clay and lime mortar, as well as in plaster and during repairs made in the past, appears satisfactory. The systems of chains, the traditional form of reinforcement, retain their effectiveness. It is necessary to insure that the chain (its anchor) distributes the loads applied to as large a surface as possible. An arcade perpendicular to the atrium entrance and a loggia above (typically single, but exceptionally a double loggia) resting on the main building, are recurring elements in the distribution of a wealthy residence in the city, but also in the countryside.

Until the late Fifteenth century, the horizontal structures are wooden, and give way to a system of masonry vaults on stone columns similar to those of the monastic cloisters. In the Sixteenth century the colder weather leads to the closure of the upper loggia in palazzo Magio Grasselli, transforming it into a gallery. The windowed wall that delimits it to the courtyard, when it is built with earthen mortar, is very delicate. It is relatively thin, generally three heads of bricks, and often is lower than the façade on the road, so that from the ridge to the middle of the building the same slope can cover the wing. To maintain the same height, they have to resort to complex secondary constructions that move the ridge of the roof and often deform and put stress onto the walls. The spans of the portico are rectangular and deep, while the vaults seen in cross-section appear as very low profile polycentric arcs.

From the middle of the Sixteenth century – palazzo Affaitati is an example – they are generally paired, forming a series of Palladian windows, and provide a more solid support. They rest on a continuous foundation that delimits a vaulted cellar of the same size as the porch and the gallery above. When excavation might damage the surrounding buildings, this solid and continuous support may be missing, and is replaced by plinths: in fact, it almost always occurs on existing buildings. This is the case of palazzo Raimondi, in the extensive and radical intervention implemented by the family Soresina-Vidoni between 1827 and 1836. The implementation of the columns is done hollowing the base and the blocks to create respectively concave and convex surfaces. This allows plumbing without the use of wedges – the results of which according to the measures are rarely satisfactory – but in turn it creates a potential hinge, which is stabilized with chains in correspondence to each column, which also supports the horizontal thrust of the arcs. When the gallery is also covered by vaults, the system, including the wooden roof, becomes even more delicate and the wall shows a projection that increases towards the centre, as it can be seen in palazzo Soldi.

In summary, a masonry made of earthen mortar is affected by any changes which may reduce the compression state to which it was originally subject, and in particular the temporary discontinuities which occur during the changes. Thick walls, and the resulting weight combined with the non-continuous adhesion of the plaster tend to accentuate cracks. Under the plaster, the variations of temperature and humidity in the masonry should be verified. Patterns of cracks, being typically the result of later changes, allow to trace the history of the buildings – providing various indications such as joints of pre-existing structures, construction choices and the stratification of changes over time. This diagnostic method, which at least in appearance is more immediate, should facilitate the choice of specific maintenance measures, but such a goal also involves the acquisition of basic knowledge which is largely missing and which the present study would, in small part, help to establish.

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