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Metal Ties in Genoa, Italy: Manufacture, Trade, and Use from the 15th to the 18th Century

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ABSTRACT

The article deals with the use of metal ties in an ancient and stratified urban context, the city of Genoa, starting from the notarial documents preserved in its State Archives. The work has different objectives: to show the results that can be obtained, on an urban scale, thanks to a research path that compares indirect sources of different types with the observation of historical buildings; to highlight the "weight" and the role that the ties, often hidden, had in buildings, and not only the monumental ones; to increase knowledge of the production process of this constructive element. The wide and diversified use of metal ties found in Genoa seems to proceed in parallel, in the 15th century, with the development of a flourishing productive and mercantile business based on the commercial monopoly of the hematite of the island of Elba by the city oligarchy and, between the 16th and 17th centuries, with the huge investments in the construction sector highlighted by the abundant documentary sources.

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1. State of the art and work objectives

In recent decades in Italy the history of construction has attracted considerable interest, as witnessed by the multiplication of conferences and publications by scholars of various disciplines. However, in the wide variety of topics dealt with, the use of ties in pre-industrial buildings and, in particular, that of metal ties does not seem to have received specific attention, with a few exceptions (Della Torre 1990, Buti 1990, Patetta 1992, Lupo 1996, Amici 2011, SSBAP 2015). This absence is probably due to several factors, including the subordinate role that the ties have compared to the essential structural components of buildings (such as masonries, floors, vaults, and roofs), its poor visibility or inaccessible position which discourages study and, not least, the idea that the iron is not so present in pre-industrial constructions, therefore, a material of little significance.

At European level the situation does not seem very different (however, see Wilcox 1981), except in France, where in recent times there has been a proliferation of historical and archeometric studies on the iron used in the structures of the great Gothic cathedrals, but not only in these structures (in addition to what is specified in the previous paragraph, see Bork et al. 2005, 245–324, L'Héritier, Dillmann, and Benoit 2007). The topics of iron production, trade and procurement strategies have also been addressed, with reference to specific territorial or urban realities, as well as to large construction sites (Braunstein 2001, Chapelot and Benoit 1985). However, these studies, even when referring to construction, contain only limited references to the manufacture or use of ties, due to their more general nature.

The real diffusion of metal ties in medieval and modern historical buildings, not only monumental, but also the actual methods of their implementation and their different functions, are therefore subjects to be explored, not only in terms of synthesis, but, first of all, on a local scale, as we try to do in this work.

This article is based on documentary research conducted predominantly on the notarial records ("*Notai Antichi*") held at the Genoa State Archive, through which it was possible to collect, transcribe and index 941 deeds relating to the building sector (building, renovation or refinement contracts for civil and religious buildings, agreements for sale or transport of raw or finished materials and architectural elements, works contracts, expense reports, testimonies, etc.) during the period between 1156 and 1724. Some of them (95 documents, i.e., 10%) contain information on metal ties (Figure 1) This research, whose general objective was to learn about past construction methods, began in 1988 as part of a university research

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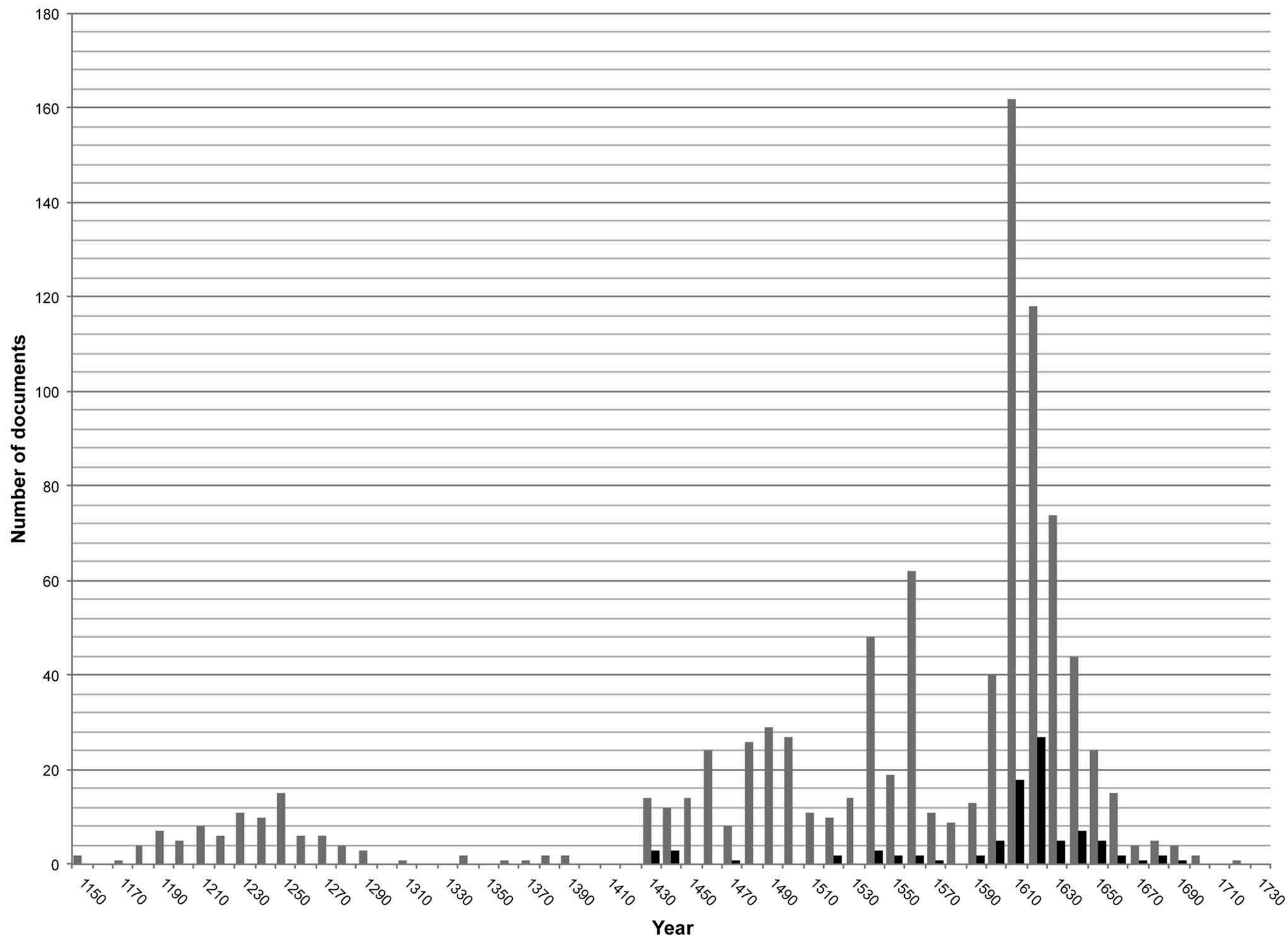

Figure 1. Histogram of notarial documents relating to the construction sector collected up to now: in gray all the documents transcribed and filed, in black the documents referring to the metal ties.

programme financed by the Italian Ministry for Universities and Research (MURST) (local coordinator: L. Grossi Bianchi, participants: T. Mannoni, A. Boato, A. Decri, and others). It then continued through doctoral theses (Boato 2005, Decri 2006) and further research, partly financed by the University of Genoa. The period investigated, therefore, expanded from 1550–1650, when the capital accumulated by the city's aristocracy during the so-called "golden age of Genoa" had significant impacts on the field of architecture (Grossi Bianchi 2005), to the 18th century, on one side (studying the work-site documentation of a family archive), and the Middle Ages, on the other.

Over the course of time, the material collected was used to investigate various aspects of buildings, specific historical periods and particular themes, such as that of old-fashioned technical vocabulary and its interpretation (Decri 2009) which is inherent in all this research.

The use of iron in the Genoese buildings between the 16th and 19th century and the less widespread use of metal anchoring systems used in Genoa from the 15th to the 18th century have been dealt with by three Italian-language papers (Boato and Decri 2000, aimed at a popular readership, Boato 2001, 2015). In the light of new research also on other sources (ironworks accounting), this article focuses on the subject of metal ties, from their use in buildings to their manufacturing methods and the trade of the relative semi-finished products. The objectives are to illustrate a particular working method and to provide information which, although referring to a limited geographical area, can be a useful element for reflection and comparison, both for other historical research and for more aware conservation or restructuring interventions. The city of Genoa, in addition to being a particularly fruitful field of study due to the richness of its archives and the presence of a broad and well-conserved historic center of medieval origin, has also been one of the iron production and trading capitals of the Mediterranean since the 15th century (Heers 1961, 219–224, Calegari 1986, Baraldi 2005). This has undoubtedly influenced the extensive use of that material in the building sector and, in particular, the widespread practice of installing visible and concealed ties in civil and religious buildings both large and small (Figure 2).

2. Research methodology

The information provided by documentary sources is, by nature, indirect. Each item of technical information deducible from the documents is mediated by the outdated language used in them. The terminology employed is, in addition, heavily influenced by the local dialect and the different languages of specific social groups or professions. One of the focal points of this article is the interpretation of vocabulary, in order to associate specific objects and building practices to each word and expression found in the documents. In the present case, it is necessary, among other things, to establish a link between the language that was used in contracts by clients and architects, mediated by notaries, to describe building under construction, the language that was used to compile expense reports and accounting ledgers, and the language of the ironworks and forges where the semi-finished products and metal elements employed in buildings were prepared.

Figure 2. Intrados ties in the 17th-century Albergo dei Poveri (Genoa). One of the ties shows a "hook-hook" joint (photo by the author).

The task of "translating" the historical terminology is partly philological and comparative within the world of the documents and words. It would, however, be impossible to achieve results without having an awareness of the building world. Parallel knowledge of the historic buildings in their material sense is therefore required and, where this knowledge is found to be lacking, further information must be gathered through targeted studies. Research in the fields of technology of historical construction and building archaeology, conducted since the 1980s, provides, in this regard, a sound although not exhaustive starting point (Boato 2008, Boato and Mannoni 1998, Boato and Vecchiattini 2011, Buti 1990, Galliani and Mor 2006). Each field study conducted in view of works on historic buildings and every restoration site is a potential source of new informative data. If read in parallel, the respective informative potential of documentary and material data is increased, and it allows to draw a far more detailed historical picture than what could be derived from a single study.

Documents have the power to "photograph" what was built and how during the different periods of history and to provide us with information on the players in the game. By comparing numerous documents, it is possible to perceive which were the recurring choices and the construction principles to which builders adhered, provided that these documents are read and interpreted with proper care and attention. Archaeological and architectural surveys conducted on existing buildings document the technical choices for each period, and the "historical depth" of buildings.

In the lucky coincidence of having a building contract and a still-existing building, the former is often of valuable assistance in the direct study of the latter, for example, inviting a search for hidden elements whose existence one might not suspect. Material and documentary sources therefore enable us to address the issue of construction and, in this case, of metal ties from a technological and historical perspective, as has been attempted in this article.

3. Historical evolution

3.1. *12th–14th century: an unresolved question*

The use of metal ties in Genoa in the Middle Ages is an unresolved question, due both to the scarsity of documentary citations dating back to that historical period and to the shortage of specific field studies.

We know from archival documents that, in the 12th century, domestic masonry buildings several stories high, with vaults on the lower floors, were constructed. Thrusting structures were therefore in use, although it is uncertain how the problem of containing the thrust generated by these was resolved at that time in Genoa.

In many large medieval buildings there are, or were, both wooden and metal ties, of which Wilcox (1981) gave a rich overview: for the wooden ones, the impressive enchainment at sight of the Basilica of Santa Maria Gloriosa dei Frari in Venice and other Venetian churches (Wilcox 1981, 84) or the temporary wooden ties of the Cathedral of Chartres and other French churches (Lefebvre and L'Héritier 2014, 292–294); the metal ones, present both in religious buildings, such as the Duomo of Milan (Braunstein 1985, 95, Morscheck 2005, Vasić 2015) or the Bourges Cathedral (L'Héritier 2016), as in civil buildings such as the Palace of the Popes in Avignon (Bernardi and Dillmann 2005), have been the subject of broader interdisciplinary research of the use of iron in medieval monumental buildings (for the usage of tie rods and chaining, see in particular L'Heritier 2007, L'Héritier 2012, 41–44, L'Héritier et al. 2012, Lefebvre and L'Héritier 2014, 294–295).

As far as Genoa is concerned, Wilcox (1981, 76 and 78) mentions several medieval churches with metal ties and identifies the church of San Fruttuoso di Capodimonte (late 11th to early 12th century) as one of the first examples of such reinforcement in Italy. However, these churches have undergone restoration and transformation, including the frequent replacement of the original wooden roofs of common rafters and tie beams with masonry vaults, which requires caution in considering them as examples of medieval construction techniques.

Numerous medieval residential buildings still present in the city also contain metal ties, but it is unknown whether these were installed at the time of building or added during the many operations carried out at later times. The anchors visible in a large number of external elevations do not appear to present sufficient differences in shape or size to suggest a possible typological chronology, as seems possible in other territories (for example in L'Aquila, Italy, see Bartolomucci 2018, 97–98, or in Flanders, where anchorages even in the form of dates are used, see Stroobants 1985, 278–279). The method of dating steel iron by radiocarbon measurement has not yet been tested locally which in recent years has given significant results (Leroy et al. 2015), but involves several employment difficulties and considerable costs.

With detailed stratigraphic analysis one might look to determine whether the site of the tie was provided originally or created later on by breaking into an existing wall. While signs of such breakage are often found, no exhaustive study has yet been conducted capable of determining whether this always occurred or whether there are cases of installation contemporary to buildings dated with certainty to the Middle Ages (Figure 3).

Figure 3. Anchors of metal ties in a Genoese medieval building. They seem to be added during later interventions because of their position (photo by the author).

Unfortunately, the oldest documents from the Middle Ages collected to date are ambiguous on this point. Two contracts from the end of the 12th century relating to the construction of domestic buildings stipulate that the client must provide the iron elements, without, however, specifying their nature. In the first (doc. 1, transcribed in Chiaudano and Morozzo della Rocca 1938, 128–129. The archival references of all the cited documents are in the supplementary data), it is specified only that these elements be "fixed in the wall" (*ferramenta figenda muro*). The term used (*ferramenta*), however, points to hooks for curtains or other suspended objects, hinges for doors or windows, or elements for anchoring wooden beams to the perimeter walls more than to metal ties. In the second (doc. 2, transcribed in Hall, Krueger, and Reynolds 1938, II, 119–120), once again, the reference is to generic "iron elements necessary to the construction" (*ferra necessaria operi in opere ponenda*), in which vaults are planned on the first floor. This, however, is not sufficient evidence that the stipulated iron elements also included metal ties.

An early reference to the use of ties (doc. 3) dates back to the following century. In 1248, *Benvenutus*, a mason and carpenter, committed to building a house, installing a tie to link the front part of the building to the rear (*imponere in dicta domo cathenam unam quam contineat et comprehendat ipsum hedificium ante et retro*). The verbs used, which may be translated as "hold together, join, hold in place, embrace and include", are very explicit as to the role of that tie. Its material, however, is not specified. We know that the building had to comprise one wall in masonry and the other three in timber, and that the roof would be covered with stone slabs. The fact that the owner was a *ferrario* (producer or worker of iron) and, despite this, took it upon himself to procure the stone but not the iron, suggests that the tie was of timber, like the majority of the building's structures. Another strong indication in this sense is provided by the word *catena* which, later in the documents, refers to timber elements (Decri 2009, 44, with the exception of doc. 65 of 1692 in which *catena di chiavi di ferro* appears translatable as "tie work comprising several iron ties").

3.2. The 15th century

3.2.1. First certain testimonies

It is not until 1438 that we find a clear testament to the use of iron in a system of ties (doc. 4). During that year, the city's judiciary, which was overseeing works on the port, began the reconstruction of the Loggia dei Greci, a building composed of a "star-shaped" masonry vault (probably an eight-ribbed cross vault) topped by a terrace and supported by brick pillars. Thanks to the documents and images that represent it, we know that this porticoed loggia was located in the Molo district, outside the dense, built-up fabric of the city but adjacent to the homonymous lighthouse. The presence of eight pillars (four in the corners and one in a central position on each side) shows, however, that it had to be statically independent. To counteract the thrust of its great vault, the perimeter pillars were therefore "tied together using iron ties" (*octo pilastris clavatis chavaturis feri circum circa*).

From this point on, citations become more frequent. In the construction of the private church of San Raffaele for use by the De Mari and De Nigro noble families, it was decided to install high-thickness metal ties (*claves ferreas grossas*) in the vaulted presbytery area and wherever found to be useful (doc. 6 of 1439).

At the point of the wooden floor in the hall of Geronimo Stella's house, built in 1441 (doc. 7), an iron tie (*clavem unam ferri*) of unspecified function appears to have been used in conjunction with other iron elements for anchoring the main beam (*omnem ferrum pro bordonario—bene clavare bordonarium*), together with "all other ironware pertaining to the said beam" (*omnem alium ferramentum spectantem ad dictum bordonarium*), probably referring to the long nails used to attach the joists to this beam.

It is interesting to notice that, in this same design, the creation of two buttressing arches, functioning as props, is also planned between Geronimo's house and the adjacent one. This system of supporting one building against another, made possible by the narrowness of the streets in the central districts, must have been widely used, as may be deduced from the monolithic props and brick arches still present, today, in some narrow streets and gaps between houses (Figure 4). In 1556, however, this practice was prohibited following the dramatic collapse of some such props, and house owners were subsequently invited to replace all existing props with metal ties (Desimoni 1885, 261–262). It is possible, therefore, that the use of ties, by then widely tested, was further increased by this regulation, also spreading into existing buildings that lacked them and into more modest constructions.

An early testament to the addition of a corner pillar and some ties to an older building with the precise purpose of "strengthening it" dates back to 1521 (doc. 11). In 1620, a dispute between neighbours over the anchorage of ties in a common wall was resolved by establishing that it was lawful to bore a hole in the wall, provided, however, that the ties did not protrude beyond the edge of the wall itself and that they were concealed (doc. 28). In a document from 1650 relating to the enlargement of what is now Palazzo Reale, it is stipulated that "all iron ties deemed necessary be installed in the existing part" (newly built) (doc. 54: *mettendo a lavor già fatto tutte le chiave di fero che si stimeran necesarie*).

Figure 4. Anchors of ties and monolitihic props in a narrow street of Sottoripa area (Genoa) (photo by the author).

3.2.2. Wood vs. iron

In the 15th century, timber was considered by the Genoese commissioners as a viable alternative to iron, while presumably cheaper and less desirable, in the manufacture not only of ties but also of elements for anchoring wooden beams to the perimeter walls. Indeed, in 1439, the prior and other people entrusted with overseeing the enlargement works of the Oratory of San Germano to include a new cross-vaulted apse, retain the decision to install ties made from iron or from wood (doc. 5: *cum clavibus ferreis seu ligni sufficientibus*). Ten years later, similarly, the decision on whether to use ties (*claves*), little tie rods to anchor the beams to the walls (*velle*) and anchors (*stangete*) made from iron or, alternatively, from wood falls to the owner (doc. 8: *ponere omnes et singulas claves ferreas et omnia vella ferrea ac stangetas necessarias et oportunas pro laboreriis supradictis, si id elegerit; sin autem teneantur ipsi Iohannes et Lucas ponere dictas claves, vella et stangetas de lignaminibus*). In the same century, treatisers such as Leon Battista Alberti and Francesco di Giorgio Martini mentioned wooden ties, which were evidently widespread, but suggested that they must be employed in iron for arches and vaults (Vecchiattini, in this issue). In other parts of Italy the use of wooden ties, often hidden, is predominant and prolonged over time (Della Torre 1990).

As evidence of how also in Genoa the culture of timber was deeply rooted, we can cite a summer home in which, as late as 1629, both metal and wooden ties were used, the former in the vaulted rooms of the upper floors and the latter in those of the ground floor (doc. 46). In both cases, the ties were, presumably, embedded in the walls. A similar decision was made regarding a rustic building in 1618 (doc. 25). This was probably an attempt to economize.

3.2.3. The genoese monopoly on elban iron and its impacts

The supply of and/or payment for iron by the client was a common practice in Genoa in the 15th century (docs. 6, 7, 8) and would continue into the centuries that followed (docs. 12, 14, 57, 59). Most other materials, on the other hand, were included in the total cost, or lump sum, established in the building contract. How can this be explained?

One hypothesis is that iron was particularly costly and that, for this reason, the craftsman or foreman entrusted with the work was unable to anticipate its costs. This explanation, however, while partly true, does not take into account the specific conditions of the iron market in Genoa. In this city, with its strong vocation for trade and finance, many members of the wealthiest families dedicated themselves, among other trades, to that of haematite extracted from the mines of the nearby Island of Elba. The earliest information on the import of this mineral into Liguria and the existence of ironworks that reduced it for the manufacture of iron dates back to the 13th century (Calegari 1977, 2–3 and 8–9). In the mid-15th century exploitation of Elba's mineral vein (*vena ferri*) was monopolised by a consortium of wealthy Genoese—the so-called *Maona vene ferri*—created especially for this purpose (Heers 1961, 220; Baraldi 2005, 160). The participants' interest in this venture did not end, however, with the trade of ore but extended to economic control of the entire production chain that resulted from it. Specifically, the members of 15th-century Maona: (1) actively contributed to the establishment of new ironworks in inland areas better equipped to serve this industry due to the contemporary presence of woods providing fuel and waterways as a source of motive power; (2) favored, where possible, the lands of which they were the lords and whose population was closely tied to them due to the numerous social and economic constraints; (3) leased or contracted out the ironworks to trusted persons, without taking on any business risk themselves; (4) sold those same ironworks charcoal produced in the woods owned by them; (5) extended the production network controlled by them by opening or re-opening production sites in Sardinia, Sicily and Corsica; (6) procured significant quantities of semi-finished or finished iron products as payment for the ore, over which they exercised absolute control; and (7) traded these products on the Genoese or even Mediterranean market, either directly or through intermediaries, thus multiplying their income. Subsequently, the various contractors of exploitation of the mines and import of iron into the Republic of Genoa, together with new entrepreneurial groups, inherited parts of this system whose effects continued to be felt until the 19th century (Calegari 1981, 1986).

It is clear, therefore, that the wealthiest people would have been able to easily procure iron for construction, either because they were directly involved in the market or because they knew the channels through which they could purchase it at competitive prices. Indirect evidence of this is provided by a contract from 1618 (doc. 26), through which a nobleman, Giovanni Agostino Balbi, purchased a substantial quantity of iron (from 800–1500 *cantara*, equal to approximately 38100–71500 kg) from another nobleman, Giovanni Battista Doria, both "raw" (*grezzo*) and processed (*in trappe*, i.e., in bars), during the very years in which he was building himself a palace on the new *strada dei Balbi* (or "Balbi Street"). This would explain, then, why many clients preferred to deal personally with the provision of iron for their building sites as opposed to leaving this task to others. Furthermore, the use of iron was most useful and widespread precisely in the largest and most prestigious buildings, constructed or financed by the richest citizens.

In the context of the predominance of the Maona and the development of Genoese iron entrepreneurship, it seems understandable that the use of metal ties became a widespread and appreciated construction practice in the 15th century.

3.3. After the 15th century: extensive use

With the passing of time, archival documentation becomes more abundant and contracts increasingly precise and detailed, probably with the objective of avoiding any ambiguities that could lead to arguments or disputes. This is one of the reasons why we find a great deal more information on metal ties (mentioned in 84 post-1500 documents in our database), which allow their forms and functions to be specified (Section 4). In contracts, certain expressions or ways of referring to the various building components also become habitual, with specification of the main component followed by a list of its accessories. For instance, the expression *clav ferri*, used in the 15th century to refer briefly to metal ties, is expanded as of the 16th century to become *clav ferri cum suis stangetis*, or "tie with its anchors" (doc. 13).

In this case, the increased detail makes explicit what is, in any case, implicit (a tie cannot exist without anchors).

Frequently, however, the presence of adjectives and clarifications corresponds, or seems to correspond, to a practical differentiation in either the articles or their arrangement. Greater certainty in this regard may be provided by work accounts, in which payments were noted both for materials arriving at the site and for tasks performed by the various workers, often offering information complementary to that contained in the contracts. In 18th-century work accounts relating to two significant private buildings, we find, for example, a note of "a tie piece with two eyes at one end" (*un pezzo di chiave con due occhi da una parte*) (Decri 2006, 17). This concise note enables us to broaden our knowledge of the old-fashioned vocabulary; indeed, no mention of the "eye" (*occhio*), or end loop, of the tie was found in either of the contracts examined. The presence of two "eyes" at the same end seems, furthermore, to refer to a system of connection between ties which was not particularly widespread and of which we have no other testimonies in Genoa.

4. Forms and functions

4.1. Bar shape and characteristics

Thanks to the adjectives associated with ties, we know that, in the 17th century, these existed in different shapes and levels of working precision. Mention is made, in 1613 (doc. 21), of "round" ties (*chiavi di ferro rotonde*) and, in 1650 (doc. 55), of ties consisting of *riondini*, perhaps round parts or round bars (from *riundu*, meaning "round"; Aprosio 2003). In both cases, for lexical reasons and due to the context of the document, the specification appears to be related to the section of the ties, which could be rendered circular by beating it while repeatedly and carefully turning the bar on the anvil.

The *riondini*, in turn, could be "ordinary" (docs. 19 and 20 of 1613: *chiavi di ferro di riondini ordinarij*) or "raw" (doc. 23 of 1616: *chiave […] di ferro riondino grezo*), to be interpreted, perhaps, as synonyms and indicative of a rough surface finishing (Figure 5). Bartolomeo Bianco, one of Genoa's most prominent 17th-century architects who, in the above-mentioned contracts, undertook to use "raw" or "ordinary" ties, promised, in 1629 (docs. 44 and 45) and 1633 (doc. 49) to install ties made from iron described as *polito*. The adjective *polito*, also used at that time to describe materials such as marble and timber, seems translatable as "smooth," "lustrous," or "well-finished" (corresponding to the Italian "*pulito*" and, more still, to the English "polished").

The fact that different adjectives are used by the same person reassures us of the existence of real differences and

Figure 5. Cathedral church of San Lorenzo (Genoa), roof of the left tower. The ties have an approximately circular section with a rough surface due to hammering (photo by the author).

of the intentional choices. It is not known, however, whether these differences were significant, in the eyes of the contracting parties, for reasons of aesthetics, quality or price. The latter varied depending on the working difficulty or time (doc. 42); indeed, in 1627, the work of the smith charged with manufacturing the metal components for the construction site of Palazzo Imperiale was worth 24 *soldi* per *cantaro* for the "raw" ties and 32 *soldi* per *cantaro* for those in *polito* iron (the *soldo* was one of the coins in use in Genoa and, according to Rocca 1871, the *cantaro* was a measure of weight equivalent to 47.7 kg). The semi-finished iron was supplied by the client and was all of the same quality.

By observing the shape of existing ties, it may be noted that these frequently have a rounded section but with a greater or lesser degree of precision; often, indeed, that which, from a distance, appears circular is, in reality, a multi-faceted profile that varies from end to end. Ties also exist with a squarish section (Figure 6) and, more rarely, with a flattened rectangular section (Figure 7). The variety of possible shapes and treatments explains why some contracts prefer to specify which of these must be used. In other cases, this is apparently left up to the experience of the manufacturer or to established practices. It should be remembered, furthermore, that the frequent and direct involvement of the client in procurement of the material constituted a guarantee as to its characteristics and quality.

4.2. Tie function and positioning

Through comparison of documentary sources with existing buildings, it is possible to reconstruct a relatively complete picture of the different types of metal tie work, with regard not only to the ties' position and specific function but also to their use for specific arrangements.

Figure 6. Grillo Palace in piazza delle Vigne (Genoa). Ties with a squarish section (photo by the author).

Figure 7. Cloister of Santa Maria delle Vigne (Genoa). Ties with a flattened rectangular section (photo by R. Vecchiattini).

The "photograph" provided by the documents collected reveals that ties were relatively widespread and that a variety of solutions were adopted. The data collected is not, however, of sufficient quantity and quality to permit the calculation of statistics.

Ties were generally associated with arches or vaults, so the most generic request could have been to install "ties for the vaults" (doc. 10: *le sue chiave per le volte*).

In a university study during which a survey was conducted on 186 vaults of various ages and types in Genoa and the surrounding area (Pittaluga 2001, 300), only 24.2% were found to include metal ties (19.2% of these were in the intrados and 15% in the extrados). This data appears to highlight a relative scarsity of ties to counteract the thrust of vaulted structures. As the author observes, however, there could be additional ties concealed in the extrados or perimeter which were not surveyed.

Sometimes, the ties were associated with timber roofs (doc. 15: *chiave di ferro … alla travacha di sala*, or "the iron tie in the roof of the hall") (Figure 5). In general, there was awareness that appropriately distributed ties were essential in binding the masonry structure (doc. 10: *in quel loco che bisognerà le chiave di ferro per tenere in freno le doe facie de la casa*, or "iron ties where necessary to stably hold the two façades of the house").

Their use was linked both to the idea of the "strength" (*fortessa*) of the individual structural component and to that of the "safety" of the part of the building to which they pertained (doc. 14: *ad essa volta una chiave di ferro capace per fortessa*; doc. 18: *in esso* *ercho ponerli una chiave di ferro acciò restino detti apartamenti sicuri*, or "install an iron tie in the arch to make the partition walls safe").

Sometimes, clients left their number and positioning up to the builders' experience and to good engineering practices. In these cases, the contract merely specifies the inclusion of "the necessary ties" (doc. 17: *con li sue chiave necessarie*) and their installation "as necessary" (doc. 38: *metterli le chiavi di ferro come bisognerà*) and "where appropriate" (doc. 21: *Metter le chiavi di ferro* [...] *in ogni luoco dove conviene*). More particular or wary clients also supervised the work in person or by assigning experts, in order to decide during the course of the work how many ties to include (doc. 20). Often, however, we find more specific (although, at times, ambiguous) instructions.

4.2.1. "Above," "around," "at the foot," and "at one third": position and typology of "frameworks" and ties "with braces"

Where the ties were positioned "around" the vaults (a single testament is found in doc. 22: *d'intorno*), one naturally thinks of a system of ties positioned along or internally to the four perimeter walls (Figure 8). That such an arrangement was conceived by the builders of old as a genuine integrated and structural system is suggested by the expression "framework of ties" (*telaro de chiavi*), used several times to refer to it.

Telari de chiavi were positioned in the large and small domes of the 17th-century church of San Carlo (doc. 44), where they cannot but correspond to perimeter containment systems.

In the vaulted church of San Francesco in Chiavari (Figure 9), a "framework" of this kind was installed "in the walls" (doc. 48: *il telaro per d.o volto nelle muraglie*). In one residential building, a "framework" was also positioned "above the walls," in addition to the ties installed in each of the vaults present (doc. 53). In both cases, the ties were evidently embedded within the wall.

The more descriptive form of a document from 1613, concisely translated below, confirms this hypothesis: "On the first floor, the mezzanine floor and the main floor, install iron ties in all directions, both in the main walls and in the partition walls, like a framework" (doc. 19: *Al piano delle volte delli mezzani e al piano delle mezz'arie sopra esse e sopra le volte delle camere di sala, che sono tre ordini, se li mettano le chiavi di ferro* [...] *per ogni verso in modo di telaro, tanto alle tramezzane quanto alle muraglie maestre*). Such a system, however made of wood, is illustrated in a rare executive drawing of about 1628 in Como, the caption of which bears the very term *telaro* (Della Torre 1990, 138–139). Where the ties "above" the vaults (*sopra le volte*) are the same ones that run along the walls (see doc. 19), this suggests the use of ties positioned at storey height or, at least, above the point at which the vault was set in the wall. Where, however, the use both of ties "above" the vaults and of additional ties "around" them is stipulated, the former would seem to be actual extrados ties (doc. 22: *con chiavi di ferro dappertutto di bona grossezza sopra le volte e dove fa bisogno d'intorno*, which translates as "with iron ties of adequate thickness above the vaults and, where appropriate, around these last ones").

As previously mentioned, existing buildings provide sound evidence of such ties. Where they are embedded within the vault, we can be sure of their installation

Figure 8. San Giuliano Abbey (Genoa). Tie along the perimeter wall (photo by D. Pittaluga).

Figure 9. Former church of San Francesco in Chiavari, near Genova. Framework of ties inside the walls, probably the *telaro* cited in the construction contract dated 1630 (Photo by C. Calderini).

contemporary to construction (Figure 10). Subsequent installation is possible, however, where they run freely above the extrados (Figure 11). The choice to position them on the ridge or extrados was undoubtedly intended to avoid the physical or, in spaces of considerable height, visual obstruction of intrados ties. In the case of decorated surfaces, which were the norm in the chambers and halls of modern palaces and villas, the disturbance caused by their presence could, indeed, have been significant.

One particular type of extrados tie was endowed with two diagonal elements, one end of which linked to the tie while the other was anchored to the wall at the vault's impost height (Figure 12). This was an attempt to increase the area of anchorage by transferring it downward, or toward the springing points, where the thrust is concentrated and instability can occur, as the builders of old undoubtedly knew from experience.

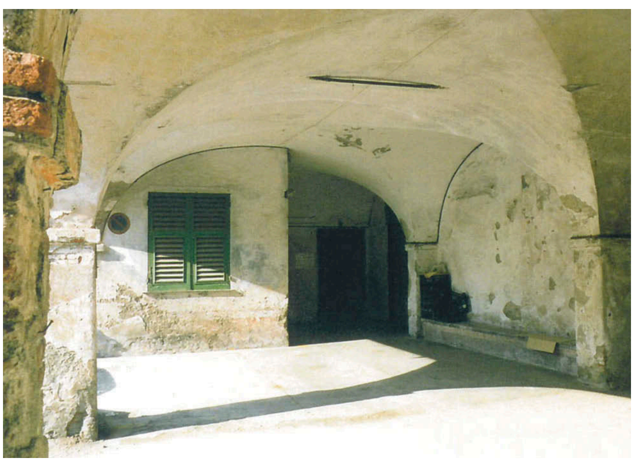

Figure 10. The so-called Saliera (salt store), in Camporone, near Genoa. Extrados tie embedded within the vault of the portico (photo by P. Cevini).

Figure 11. Monastery of Santa Maria di Castello (Genoa). Extrados ties, perhaps added because of their position above the crown of the vaults (photo by D. Pittaluga).

Several case studies testify to the use of these during the 17th century in buildings of various types, both in the city (church within the monastery of Santa Maria delle Grazie: see Boato, Lagomarsino, and Pittaluga 2003, Boato and Pittaluga 2003) and in the Republic of Genoa area (a salt store called Saliera, in Campomorone: see Cevini 1994–1995).

This solution can be found in documents referring to *chiave di ferro con suoi bracci* (doc. 31: literally meaning "iron ties with their braces"). To connect the diagonal tie to the main one, hooks (*ganci*) were heat-welded to the tie and the end of the brace was bent to form a hook (*gancio*) (Decri 2006, 17). The joint was, therefore, of a "hook-hook" type (Spalla and Arvigo Spalla 1992, 33), which allowed some movement between the parts (Figure 13).

In this particular arrangement, the use of "*riondini* for *stanghette*" (doc. 34: *riondini per stanghete*), or elements with a rounded section as anchors (*stanghette*), appears significant. Indeed, the anchors used in Genoa were normally wedge-shaped in order to better hold the ties and put them under slight traction (Figure 14). However, it was inconvenient to use a wedge-shaped element if this had to pass through two eyes, as was advisable in order to integrate the brace with the tie. This explains the use of simple rounded bars of uniform section (Figure 15), which could be locked in place using iron wedges. These bars could reach up to 2.5 m in length, as found in a building situated at no. 1 Via delle Fontane (Galliani and Mor 2006, 108).

The tie could also be endowed with a single brace, presumably due to asymmetry in the structure of the building and the arrangement of its rooms (doc. 35: *4 chiave de ferro […] e due di esse da una parte li suoi bracci*, or "4 iron ties, two of which with braces at one end"). This instruction was observed in relation to the transverse ties of the portico of the *Saliera* (salt store) in Campomorone, whose vaults are, on one side, built against other rooms and, on the other, open to the central courtyard (*all'incontro di ogni pilastro le chiavi di ferro con il suo brazzo verso il cortile*, or "at each pillar, the iron tie with its brace towards the courtyard"; Cevini 1994–1995, 38).

The idea of a "framework" of ties (*telaro*) associated with the presence of "braces" typical of extrados ties, which emerges from some documents, is something of a puzzle.

One possibility is that it is the single ties of the "framework" that are to be endowed with braces, which could be the case if the ties are, for example, positioned above the arches that support the dome (as suggested in Dotti 1730, 4, which uses the term *telaro*, as in Genoa). However, in doc. 43, which stipulates the installation of a "framework of ties with braces" in all the vaults, only cloister vaults are

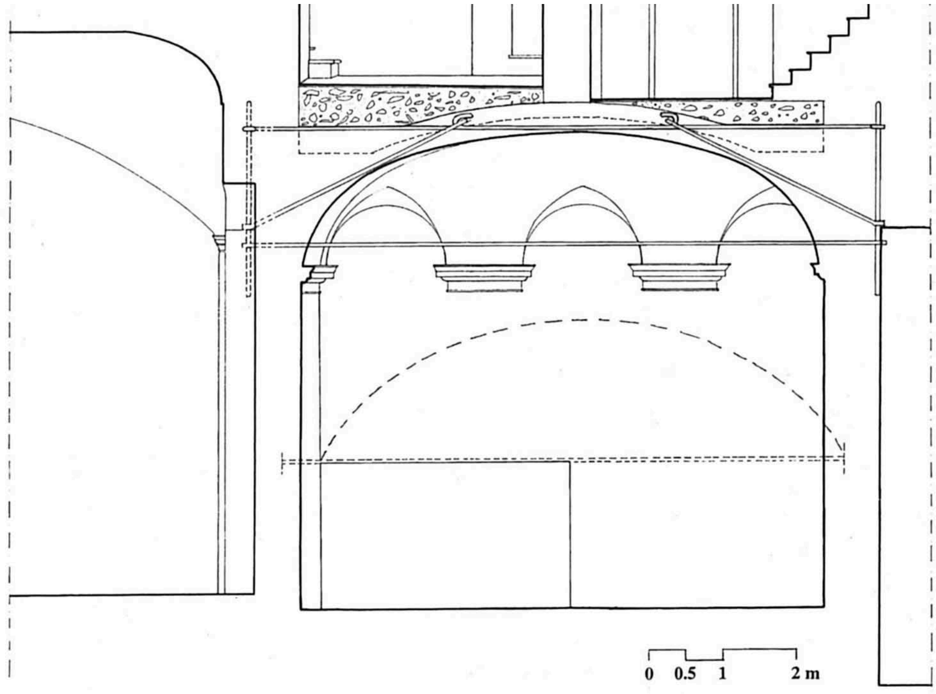

Figure 12. Internal curch of the Monastery of Santa Maria delle Grazie (Genoa). Cross section that shows the remarkable system of ties including intrados ties and extrados ties with diagonal "braces" (drawing by A. Boato and M. Sarcina, from Boato and Pittaluga 2003, 101, modified).

Figure 13. Palazzo Ducale, vault of the hall (Genoa). Joint of a "hook-hook" type between the extrados tie and its brace (from Spalla and Arvigo Spalla 1992, 33).

Figure 14. Wedge-shaped anchor of a tie in a Genoese building (photo by the author).

mentioned. An alternative possibility is suggested by a document from 1626 which indicates that the tie endowed with braces was added to the more habitual (and, one might think, ubiquitous) framework (doc. 41: *le chiavi di ferro con braci e stanghete oltre al solito telaro che si metterà ad ogn'ordine di volte*, or "iron ties with braces and anchors as well as the usual framework that will be installed in vaults of all levels"). The co-presence of these two systems was therefore so habitual that there was no need to waste time in illustrating it. This would explain, then, why this and other documents briefly stipulate the use of "ties with anchors, frameworks and braces" (doc. 41: *chiavi di ferro con stanghete telari e bracci*) without distinguishing the various roles and positions of each of the elements listed.

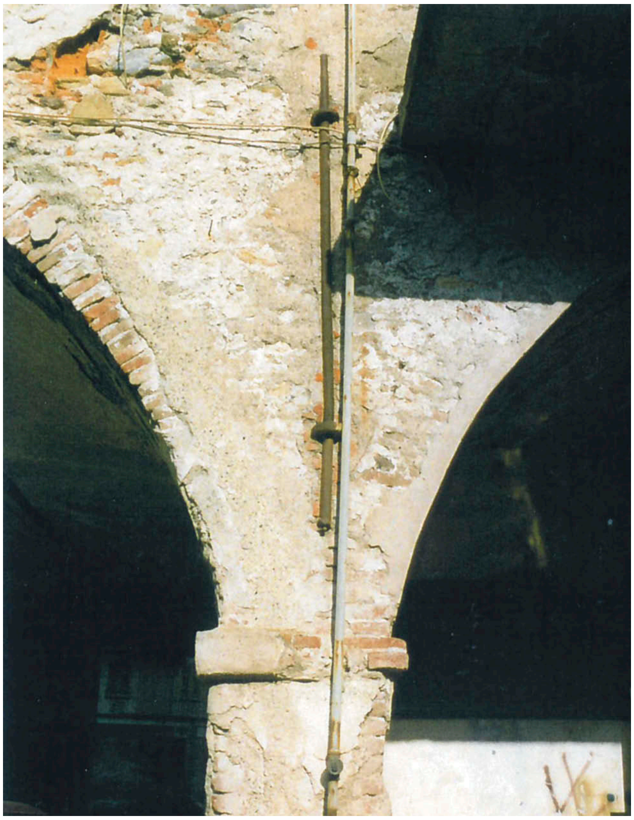

Figure 15. The Saliera, in Campomorone, near Genoa. Anchor made by a bar of uniform section to hold both the extrados tie and its brace (photo by P. Cevini).

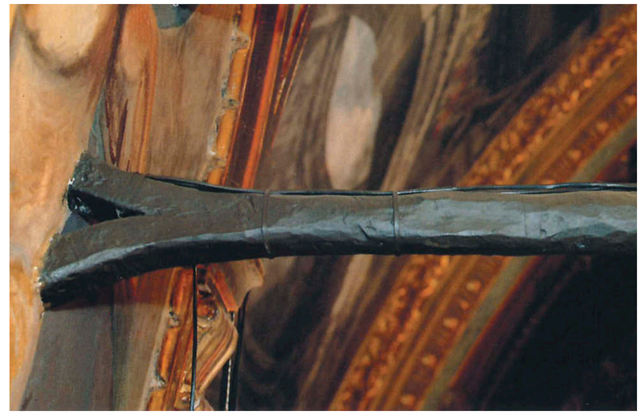

Figure 16. Cathedral of Nostra Signora dell'Orto in Chiavari, near Genoa. Intrados tie which forks into two branches (from Montagni 1993, 192).

Similarly, the repeated instruction to position the tie endowed with braces "in the foot" (docs. 34, 39, and 50) or "at the foot" (docs. 31, 32, and 41) of vaults, i.e., in their lower as opposed to upper part, as one would expect, is perplexing and requires consideration of the possibility that the braces had diversified dispositions and functions. In Chiavari Cathedral, intrados ties exist that fork just before the walls to which they are attached (Montagni 1993, 192). The two branches into which these ties divide can certainly be associated with the idea of two braces (Figure 16). The advantage of this configuration could lie in the fact that it spreads the traction force over a larger wall area. In the structure with pillars and crossed arches of the 17th-century Arsenal, the stumps of transversal intradossal ties have been identified, provided with braces with a hook union similar to that of Figure 13, but placed flush with the arch: this is probably a way to better anchor the tie to a pole hidden in the pillar or, perhaps, to connect it to the longitudinal ties (Pittaluga and Canziani 2006). In the 19th-century Quezzi tower, on the other hand, the forking of only one end of some ties is connected to the presence of machicolation slots at the exact point where ordinary ties would have ended, and this forking into horizontal braces provides anchorage at the point of the masonry pillars instead (Schiappapietra 2011/12, tables 12 and 13).

The fact remains that a discrepancy appears to exist between the frequency of documentary references and the rarity of forked ties actually found. While this author tends to believe that the way in which they are described in contracts is generally accurate, one cannot help but think that the recurring expression "position at the foot of the vault the tie with its braces" should be read with its components inverted, based on a document that reads as follows: "iron ties with their braces at the foot of the vaults" (doc. 32: *chiave di ferro con suoi bracci a piedi delle volte*). Indeed, this document seems to place the emphasis on the low positioning of the braces as opposed to of the ties.

It is therefore clear that only through the reading and comparison of many documents together with parallel study of actual situations we may avoid to fall into the trap of reading these documents too literally with too much trust in their precision.

As we have seen, ties with braces are often positioned, according to contracts, "in the foot" or "at the foot" of arches and vaults. We find a similar instruction related to ties without braces (docs. 30 and 55), which could be considered equivalent to the expression "at the impost" (*ala inpostta*, doc. 33: *uno corso de ciave al piano di sala ala inpostta de i voltte di fero*). In buildings, it can be observed that the ties are not always positioned at the same height but relatively higher or lower. While it is true that shades of meaning could be attributed to the different expressions, it is probable, however, that these were used indiscriminately to indicate the lower third of the arch. In only two cases—perhaps not by chance relating to churches (buildings of particularly demanding construction)—the instruction is more specific, indicating "one third" of vaults and arches as the most suitable height for installation of the ties (doc. 44: *in l'altezza del terzo del volto*; doc. 55: *al terso di detti arconi*).

4.3. Dimensions

The diameter of the ties is specified in just one case (doc. 44), in which it is required to be at least two and a half *once* (approximately 5 cm. For the conversion of linear measurements: Rocca 1871). Sometimes, the weight is stipulated (doc. 16: approx. 16 *rubbi*, equivalent to about 127 kg, for each tie; doc. 65: 12 *cantara*, equivalent to about 572 kg, for tie work situated on the vaulted first floor of a building measuring approx. 17.5 × 14.0 m, presumably consisting of a sequence of several ties. For the conversion of old Genoese weights: Rocca 1843, table II). Some surveys estimate the weight of ties already installed (doc. 9: 2 ½ *cantara* and 2 *rotoli*, equivalent to 120 kg, for a tie and its anchors; doc. 43: 10 ½ *cantara* and 7 *cantara* for two groups of ties, from which an average weight of 167 kg may be calculated). The weight was important because it determined the price; indeed, ties, like other iron elements, were valued and paid for based on their weight. However, their weight also provided an indirect indication as to their required thickness, since the size of the rooms and the distribution of the ties were known to the contractors.

With regard to anchors, a contract for a summer home (doc. 56) required them to be 4 *palmi* (about 1 m) long. The contract for the construction of the church of San Geronimo and San Francesco Saverio (doc. 55) required them in two different sizes: 5 *palmi* (approx. 1.25 m) for the anchors for the ties on the lower level and 6 *palmi* (about 1.5 m) for those related to ties on the higher levels. It was also established that those of the church's perimeter should be "proportioned" to the relative ties.

In this same building, we note that *chiavi di 3, di 4*, e *di 6 a fascio* (literally, "ties in 3, 4, and 6 per bundle") were required to be used. What is the meaning of this strange expression, found in various documents starting from 1616 (docs. 23, 35, 36, 37, 40, 41, 44, 46, 47, 49, 50, 51, 53, 55, 56, and 63), also in the form "ties 'of' n per bundle" (*chiavi da* n *a fascio*)?

"Ties of *riondini* in 1 per bundle" are also mentioned in doc. 55 and, similarly, "in *riondino* of 4 per bundle" in doc. 38. In many documents (docs. 29, 30, 31, 32, 34, 36, 39, 48, and 52), the ties are defined as "of *trappe* of n per bundle", where n varies from 1–6.

We know that *trappe* were traded at least since the 16th century. A contract of 1560 for the supply of generic "iron elements" for a palace under construction relates to "iron elements in bundles of *trappe* of 4, 6, and 8 *trappe* per bundle" (Poleggi 1972, 113). Montagni (1993, 293) transcribes a contract for the purchase of "assorted *trappe* of 2 to 14" whose intended use is not clarified. *Trappe* "for curtains" and "for gratings" are mentioned in commercial contracts dated January 12, 1521 and June 5, 1523 (ASGe, NA 1554).

In Genoese dialect, a *trappa* is a long, thin, straight and rounded bar of any material (Casaccia 1851). In conclusion, *trappe*, like *riondini*, are undoubtedly bars which, when welded in sequence, constitute the tie ready for installation. They could be of greater or lesser thickness, thus determining the thickness of the tie (doc. 42: "ties of *trappe* of the thick type, like those of a church").

As previously mentioned, the number of tie *trappe* in a bundle was always between one and six. The most common were those "of 4 to a bundle," as underlined in doc. 52. In doc. 39, it is specified that the *trappe* of the ties had to be "of 4" and those of the relative braces "of 6." In doc. 53, the ties of the vaults were required to be "of 4" while, for the *telaro* (framework), it was sufficient to use those "of 6," thus establishing a clear hierarchy associated with their different structural roles. Ties "of 1," "of 2," and "of 3" were used in more demanding constructions (church vaults and domes). *Trappe* in numbers varying from 4 to 14, on the other hand, were used in window gratings (Decri 2009). Those greater in number were, therefore, smaller in diameter. What was the rule governing this relationship? The following is deduced based on additional data and through various logical steps (using new data to qualify the proposals of Boato 2015).

The accounts for the transport of products manufactured at the Tiglieto abbey ironworks from the production site to the port of Voltri systematically refer to bundles of various products including iron simply qualified as "of 2," "of 3," "of 4," "of 5," "of 6," "of 7," "of 8," "of 10," "of 12," "of 14," or "of 16" (docs. 61, 62, and 64). The correspondence between these expressions and the contents of building contracts appears significant.

The goods were transported on mule back. The unit of measure used to pay the mule driver, however, was not the "bundle" (a word which refers to the packing of the material) but its weight. The accounts examined always consider pairs of bundles, whose weight varied from a minimum (exceptional) of 1 *cantara* and 65 *rotoli* to a maximum of 2 *cantara* and 85 *rotoli* (from 78.6 kg to 135.8 kg).

Construction contracts also mention "bundles" consisting of a single bar, which therefore had no need for particular packing or binding. When putting the bars together, what counted, then, was the overall weight, whose transportability needed to be ensured.

In the Liguria region, the network of routes linking the coast to the interior, where the iron production centers were situated, consisted mainly of paths which were often steep and winding. Along these routes, transport of iron ore and semi-finished and finished products was normally by mule, as widely documented for the Tiglieto ironworks (Casaleggio 2004, C). Carts do not appear to have been used until the late 18th century and mainly in the 19th century, on certain routes (Paoletti 1991, 654–6). In Genoa, the *soma* (meaning "load placed on the back of pack animals") for lime was equal to 16 *rubbi*, or 127 kg (Rocca 1871, 105). In 1754, the weight of a *soma* of sand was considered equal to about 3 *cantara*, or about 143 kg (Decri 2006, 30). These values, certainly comparable to the maximum found in the transport of iron bundles, provide a clear indication of the load that a mule could carry in the Liguria of the past.

Returning to the subject of iron elements "of n," the average weight of two bundles calculated from a total of 181 pairs of bundles transported between 1682 and 1684 is 2 *cantara* and 51 *rotoli* (119.6 kg), giving an average weight per bundle of 60 kg. The distribution of weights (from 2.04–2.85 cantara) is a symmetrical Gaussian curve peaking at the value of 2.50. For the purposes of our reasoning, we can assume that the bundle had a constant or standard weight, equal to the average weight. It is probable that the length, too, was relatively constant, as well as contained, so as not to impede the animal's movement.

If the overall weight and the length of the bundle were constant, the volume of the material and, consequently, its section, must also have been constant (considering full loads only). It follows that the section of the bars contained in a bundle must have been inversely proportional to their number.

It can therefore be deduced that bars "of 14 per bundle" had a section 14 times smaller than those "of 1 per bundle." Their diameter, in turn, varied according to the area of the section. Based on the bars of average-sized window gratings, which, in 17th-century documents, are "of bars of 8" and, in the corresponding buildings, have an average diameter varying from 2.5–2.8 cm (Ariberti 1996/97, 143–144), the diameters of all other types of *trappe* can be obtained (Table 1) by calculating the theoretical total section of the bundle (39.3–49.3 cm^2). The thinnest ones used for 17th-century ties ("of 6 per bundle") would therefore have had a diameter of 2.9–3.2 cm, the thickest a diameter of 7.1–7.9 cm and those "of 4 per bundle" (most frequently used) a diameter of 3.5–4.0 cm. These values are coherent with the little data actually known (Ariberti 1996/97, 144, Boato and Pittaluga 2003, 107, Pittaluga and Canziani 2006, 136 and 138, Boato 2015, 414, Calderini et al. 2016, 1296), confirming the above reasoning.

Based on the theoretical total section and the "specific gravity" (specific weight) of forged iron provided by Cavalieri San-Bertolo (1826), which varies between 7600 and 7800 kg/m^3 depending on its state of greater or lesser purity, we can obtain bar lengths varying between 1.6 and 2.0 m (Table 2), compatible with the transport problems mentioned previously and coherent with the available survey data (Boato and Pittaluga 2003).

The absolute results obtained are, of course, affected by many uncertainties, not least the product variability inherent in pre-industrial manufacturing processes. In the absence of a database of existing elements providing actual measurements, those hypothesised appear to have correct orders of magnitude.

5. Production, processing, and trade

5.1. Workmanship in smithies or on construction sites

As we have seen, ties were composed of several elements (*trappe*), which were welded together in an

Table 1. Calculation of the theoretical thickness of the *trappe* (bars) contained in a bundle "of n *trappe* per bundle."

				from	to	
diameter of 1 *trappa* of 8 per bundle (from Ariberti 1996/97)				2.5	2.8	cm
area of the cross section of 1 *trappa* of 8 per bundle				4.9	6.2	cm^2
total section of a bundle (area of 1 *trappa* x 8)				39.3	49.3	cm^2
	area of the cross section of 1 *trappa* (cm^2)		diameter of 1 *trappa* (if round) (cm)		side of 1 *trappa* (if square) (cm)	
trappe per bundle	from	To	from	to	from	to
1	39.3	49.3	7.1	7.9	6.3	7.0
2	19.6	24.6	5.0	5.6	4.4	5.0
3	13.1	16.4	4.1	4.6	3.6	4.1
4	9.8	12.3	3.5	4.0	3.1	3.5
5	7.9	9.9	3.2	3.5	2.8	3.1
6	6.5	8.2	2.9	3.2	2.6	2.9
7	5.6	7.0	2.7	3.0	2.4	2.7
8	4.9	6.2	2.5	2.8	2.2	2.5
10	3.9	4.9	2.2	2.5	2.0	2.2
12	3.3	4.1	2.0	2.3	1.8	2.0
14	2.8	3.5	1.9	2.1	1.7	1.9
16	2.5	3.1	1.8	2.0	1.6	1.8

Table 2. Calculation of the length of the *trappe* (bars) using the following formulas: average weight of the bundle/specific weight (variable) = volume of the bundle; volume of the bundle/area of the cross section (variable) = length of the bars.

average weight per bundle	specific weight of forged iron (Cavalieri San-Bertolo 1826)	volume of 1 bundle	area of the cross section of 1 bundle (from Table 1)	bar length
kg	kg/m^3	m^3	m^2	m
60	7600	0.0079	0.0039	2.01
60	7800	0.0077	0.0039	1.96
60	7600	0.0079	0.0049	1.60
60	7800	0.0077	0.0049	1.58

operation known as *bollitura* (forge welding) both in modern Italian and in the old vocabulary (Decri 2006).

Each bar was welded to the adjacent one by overlapping their respective ends, which were previously thinned, and heat-beating them while turning them (Valadier 1828–1839, II, 170). In installed ties, the welding areas (around 12 cm) are often recognizable by their different thickness or, where the bars show signs of hammering, by the rotation of these traces from one segment of tie to the next one (Boato and Pittaluga 2003). A certain breadth of weld obviously ensures a better seal.

Contracts for the supply of iron elements are rather rare. We therefore do not know if, as a rule, the welding of ties, especially the longest, heaviest and most difficult to handle, was carried out in the blacksmith's workshops or, rather, on the construction site, to avoid transport problems. When the contract provides for both the manufacture of the ties and their delivery (doc. 42) or when the manufacturers are asked to provide workers for their transport to the building (doc. 24), the blacksmith can be considered to have worked in the shop. However, the presence of a smith with a forge (*focina*, doc. 58), equipped with anvil and bellows (doc. 60), is documented in the great 17th-century building site of the Albergo dei Poveri, a hospice for the poor. In this way, all iron working necessary for the preparation of ties and other building elements and for maintenance of work tools was performed.

Workmanship contracts required the client to supply the iron, with the specifications that the smith returned that same iron once forged (doc. 42) or that it did not mix "old iron" with "new iron" received (doc. 27). There was evidently concern that the smith might use lower-quality iron of a different origin. Instead, the clause which provided for the return of a load of "worked iron" equal to the weight of the "raw iron" received was of an economic nature: any consumption of the metal during processing remained "to the detriment" or "at the expense" of the smith (doc. 54; contract of 1656 transcribed in Montagni 1993, 294).

The detailed contract signed for the Albergo dei Poveri specifies that it will be necessary to "test the strength of the ties before installing them" and that, if they are not sufficiently strong, the smith will be required to set them right (doc. 60). According to Valadier (1828–1839, II, 170), this test was performed by throwing the tie from a certain height onto a pavement or stone floor.

The points considered weakest were the joints (*gionture*), hooks (*ganci*), and, in general, those points where different parts were joined together (*attacchi*), which could "come apart" or "give way" when subjected to stresses. The smith was held responsible for any breakage that occurred in the parts hot-worked by him, but not for the quality of the bars that were supplied to him. Indeed, through forging, he was able to distinguish good iron from bad. Poor-quality iron, according to the opinion expressed in the document, was characterised by the presence of *sfoglie* (literally: "flakes"), perhaps flaking caused by hammering, known in Italian as *sfogliature* ("flaking"). Iron that was "brittle" (*agro*), i.e., hard, fragile and difficult to work, was also considered poor quality (Varagnoli 1996, 429).

From 18th-century expense lists relating to a significant renovation (Decri 2006, 11–12), we also know that previously installed ties could be cold-"cut" and subsequently "heated" and "turned" (*rivoltate*), in other words, perhaps, bent into a U shape in order to be joined or anchored. The cutting of "installed" ties and anchors to adapt them to new requirements was performed using *lima* (file), perhaps in association with an "archetto" (literally, a "small bow"), meaning a small bow saw. Both ties and anchors could also be "straightened" (*adrizati*), to rectify the deterioration suffered. Straightening of a pre-"heated" (*scaldato*) anchor was undoubtedly performed after removal from its site, where the operation would have been impossible. As far as ties are concerned, it is difficult to imagine that straightening and, even less, welding (*dato tre bolliture*, meaning "performed three welds"), could have carried out *in situ*, where it would have been difficult both to adequately heat the iron and to hammer it evenly and effectively.

A final note concerns the recovery of old ties and their rework to adapt them to a new usage (doc. 42): in addition to the more general indication of "recreate" and "accommodate," also *agiongere* (translatable with Italian *aggiungere*, in English "add") is foreseen, which may correspond to the need to weld new iron to lengthen them, all at the same price provided for the manufacture of new well finished iron ties. The practice of iron recovery, well documented in French Gothic monuments where it was implemented in different ways according to the needs of employment (Dillmann and L'Héritier 2009), also comes into play in Liguria in the course of smelting the mineral, as will be seen in the next section.

5.2. From raw material to semi-finished product

Ligurian ironworks have been the topic of much research which, over more than 50 years, has examined this subject matter from the viewpoints of historical technology, the origin, distribution and type of the establishments, the role of Genoese businessmen, and its social and economic impacts (Faina 1966, Baraldi and Calegari 1977, Calegari 1977, Baraldi 2005, among others). Thanks to the preservation of several private archives and a kind of manual drawn up by the owner of an ironworks, it has been possible to analyse the activities of certain establishments operating in the late 17th and the 19th centuries (Baraldi 1984, Bartolomei 1977, Casaleggio 2004, Paoletti 1991). The vocabulary of establishments, equipment, materials and products has been studied through Inventories, lease and management contracts and an interesting first-hand testimony (Baraldi 1979, 1986). The historical evolution of specific establishments has been examined (Rossi 1989). Some of these publications offer starting points for the study of the semi-finished products and finished elements used in the building sector, including ties.

It should be underlined, first of all, that in the Early Modern Period, the consumption of iron in the city appears to be satisfied by local production, with plants that date back at least to the 13th century and that in the 14th century we know to be equipped with hydraulic systems (Baraldi 2005). Some rare references, in the 15th century, to the presence of iron from Biscay, steel from Lombardy and bales and bundles of iron exchanged in Genoa between Lombard merchants (Heers 1961, 220) seems marginal. However, it should be better investigated because it could be an indication of the heritage of the centuries that preceded the creation of the Maona, when the market was perhaps more varied.

The wide-ranging iron objects produced by Ligurian ironworks, and placed on the market were all manufactured based on the same mixture (see further) and the same reduction process (traditionally, but not exclusively, direct method or bloomer smelting, Calegari 1977, 1986, 4, Baraldi and Calegari 1977, Baraldi 2005), using (generally chestnut) charcoal (Bartolomei 1977, 46, Baraldi 1984, 40 and 66, Paoletti 1991, 661, Casaleggio 2004, XCII). The differences between the various finished and semi-finished products (from nails to bars, from circles for barrels to agricultural tools, etc.), therefore, lay predominantly in the beating process, of varying length and difficulty, necessary to give shape to the various products, and in any hardening and steeling processes used, also performed on construction sites for maintenance of work tools (Decri 2006, 11).

The raw material consisted of haematite originating from the Island of Elba, with the exception of limited attempts to use local ore (Heers 1961, 219, Pipino 2005) and some information about the presence in Genoa in the 15th century of minerals from the Basque Country (Heers 1961, 220), of which we do not know if only in transit or to be used locally. Several changes took place over time: in particular, from the end of the 16th century, many ironworks systematically mixed *ferraccio* or *ferrro agro* (cast iron produced in blast furnaces) and scrap iron with the ore to accelerate the smelting process (Calegari 1977, 15 and 21). In this period, and presumably even after that, the cast iron was purchased in Tuscany, from whence sea transport was easy and cheap, and where it was produced from the same ore (Calegari 1977, 21 and 30). The scraps originated from the same areas in which the ironworks sold the wrought iron (Bartolomei 1977, 49), although it cannot be ruled out that old pieces of iron might arrive as ballast for ships from other Mediterranean ports (Baraldi 1984, 68). We can assume, then, that the composition of the ductile iron produced did not undergo any significant changes as a result of this innovation. Differences could, however, have existed with regard to the presence of greater or lesser impurities and the grain of the metal. Indeed, these characteristics depend on the accuracy of refining performed by beating in ironworks.

The minimum equipment of an ironworks consisted of a furnace, the ventilation systems connected to it (bellows or, from the 17th century, trompes, as reported in Calegari 1977, 23–24, Baraldi 2001, 205) and a trip hammer operated by a water wheel, hammer which, in the 15th century, became heavier (Baraldi 2005, 164). All authors agree that the product of the first stage of hammering ("purged iron," Baraldi 1984) was the so-called *quarone*, a thick iron bar obtained by beating, subdivision into two pyramid-shaped pieces (*tronchéij*), heating and re-beating of the mass of metal (*massé*) extracted from the reduction furnace, as described in the memoirs of a witness, Luigi Bazzano, collected in a manuscript from 1923 (Baraldi 1979). According to Bazzano, the *quaròn* had a square section of 6 cm on each side (*ibidem*, 179), slightly less than but comparable to that of the thicker 17th-century bars "in bundles."

The *quarone* could be traded in that form or reduced into thinner bars. We have evidence of the trade, in the 15th century, of both *quayronis* (1491) and *staziole* (1455), the latter being sold in bundles weighing a maximum of 1 *cantaro* and 10 *rotoli* (52.4 kg), each containing 5 or 6 *staziole*. In 1460, *stazie large*, undoubtedly different from the previous ones and perhaps flat and broad (*large*), and *verzelote* were traded (Baraldi 2005). In the latter half of the 18th century, the principle semi-finished products manufactured from the *quarone* at the De Ferrari ironworks in Voltaggio were called the *stazola*, the *verzelina* and the *dapiano*. Their relative sales prices increased in that order but, oddly, their manufacturing costs did not, being lower for the *stazola*, medium for the *dapiano* and higher for the *verzelina* (Bartolomei 1977).

All texts agree that the *stazola* was a quadrangular bar, the *verzelina* was a round bar and the *dapiano* was a flat bar, although no data is given to support this interpretation. All these bars were produced in *maglietti*, smithies often associated with ironworks, where there were smaller hammers (*maglietti*, literally meaning "small trip hammers") with relative furnaces for heating the workpieces. According to Bartolomei (1977) the output of such workshops may also have included finished products, including nails and rods of various sizes together with *stanghette* (anchors) for ties.

5.3. Which semi-finished products in the manufacture of ties and anchors?

As to which semi-finished products were used for the manufacture of these rods or, more generally, of bars for ties, we have no certainty at this point. Some information is provided by documentation relating to iron ore and wrought iron import licensing and collection of the related taxes and penalties. The so-called *devetum* (literally meaning "ban") was periodically contracted out to the highest bidder. Based on a regulation of 1539, the winner of this lucrative contract undertook, in exchange, to "keep the city supplied with iron in the form of *stagis* (or *stangis?*), *stazolis* (or *staziliis?*), *rondinis*, and *stanghetis*, for use in the building of ships and the construction of houses" (Di Tucci 1929–1930, Anno VI-1930, fasc. II, 147, Felloni n.d.).

There are some notable links with the vocabulary of building contracts. As we have seen, *stanghette* used on construction sites are anchors. *Riondini* are bars, presumably rounded, also used for the manufacture of ties. *Stazole* are mentioned in two 17th-century documents as semi-finished products used for the small tie (*vela*) which, anchored by a *stanghetta*, connected the ends of wooden beams to the walls (docs. 20 and 25). *Vele*, widely used, including in the cross-beams of floors, were made using a flat iron element which could easily be nailed to the beam (Montagni 1993, 141 fig. 91). *Stazole* could therefore be flat bars (Decri 2009, 121) rather than quadrangular ones as maintained by publications on ironworks. They would not, then, appear to be the type most frequently used for manufacturing ties in Genoese houses, although one 18th-century document mentions *chiavi di stazza e stanghette*, or "*stazza* ties and anchors," where the word *stazza* could refer to a *stazola* (Decri 2006, 18).

Returning to the vocabulary of ironworks, it can be observed that the above-mentioned *dapiano* could take various forms. Indeed, a second study of the De Ferrari ironworks in Voltaggio specifies the existence of a "*dapiano* in plates," a "square *dapiano* in *trappe*," and a "broad and thin *dapiano*," which could be subjected to further processing in order to become, among other things, cart wheel rims or cask hoops (Paoletti 1991, 713). The term *dapiano*, which sounds like the Italian word "piano" (meaning "flat"), presumably originates from the shape of the hammer head, which, if wide and flat, permitted the manufacture of smooth, squared bars free from the signs of beating left by a sharp hammer (Sergent n.d., 175–176). It does not necessarily refer, therefore, to a flat iron implement. The term "square *dapiano* in *trappe*," in particular, appears compatible with the *trappe* (bars) of ties, something which remains to be ascertained through further research.

The terminology of ironworks products in their various stages of manufacture is therefore highly complex and varies from the simplified terminology indicated in many publications.

The Tiglieto abbey ironworks, at the end of the 17th century, sold large quantities of bundles from "of 2" to "of 16," as we have seen, in addition to other products (docs. 61, 62, and 64). Bundles of *stazola*, a name we have already come across, are mentioned as well as *stanghette*, both loose (counted as individually: *pezzi due stanghette*) and in bundles. Two items (to be read as two *stanghette*) weighed around 1 *cantara* and 60 *rotoli*, equal to 38 kg each, compatible with an anchor two metres long with a side section of 5 cm. *Stanghette* transported in bundles could also be "of 3, of 4, of 5, of 6, of 8, of 10, of 12, of 22 or of 24." *Stanghette* of 3 per bundle must have weighed an average of 20 kg. Those of 24 per bundle, on the other hand, would have weighed about 2.6 kg, therefore being fairly small but compatible with smaller anchors.

This ironworks also sold more limited quantities of iron elements defined as: "*tondo* of 3" and "of 14" ("round" of different thicknesses?); *piato*, also specified as "of 4, of 6, of 8, of 14, and of 16" ("flat", of different thicknesses or widths?); *quadro*, also specified as "of

14" and "of 16" ("square," of different thicknesses?); and *ponentino* (an adjective which, in Italian, means "from the West" but, in this context, is of unclear meaning). All these adjectives are also documented in the 18th-century works accounts of two significant residential buildings (Decri 2006, 16–17). Unfortunately, these do not specify the intended use of the various iron elements.

Some shipments, finally, related to "*trappe* of 14" and "of 16." Given their reduced size, these could be identified as the bars referred to elsewhere as "*trappe* da vetro" (Calegari 1986), i.e., the bars used to support glass window panes (Decri 2009, 128).

In conclusion, the multiplicity of nouns and adjectives used to refer to the products of the Tiglieto ironworks do not appear limited simply to the form of their section but also to differences currently unknown to us. Furthermore, while it is true that many adjectives appear to refer precisely to their form, what form, unlike previous ones, could characterise the simple iron elements "of 2," perhaps used in ties?

6. Concluding remarks

The absence of clear documentary references and archaeological verifications of Genoese medieval buildings with ties does not allow us to say that they were already in use before the 15th century. However, this is very likely, in the light of the testimonies, also iconographical (from the end of the 13th century), which have been highlighted in many Italian regions (Patetta 1992, Wilcox 1981). It is certain, however, that they were used in public and private buildings, religious and civil, in the 15th century (first reliable quotation: 1438). This has been connected with the simultaneous intense development of the trade in Elban ore and Ligurian iron production by the Genoese oligarchy, but is also consistent with the extensive use of the metal ties observed in nearby Tuscany and other parts of Italy (Patetta 1992, 235–238).

As far as the Early Modern Period is concerned, the numerous contracts collected from the 17th century show an extensive and varied use of ties, both in churches and residential buildings. From them derive interesting indications about their disposition and their function (both the one attributed in the past by the builders, and the one we can hypothesize). As for the dimensions, a curious aspect is that of the thicknesses, indicated only indirectly through the reference to a transport unit, the bundle (*fascio*). The cross reference of construction contracts and the commercial accounting of the ironworks has made it possible to arrive at a satisfactory explanation of the expression "ties in 1, 2, or n per bundle" and to determine the correspondence between this indication and the actual section of the ties, which must now be verified by systematic direct measurements.

In general, the analysis carried out on the texts and the repeated interpretative doubts still present highlight the usefulness both of an increase in the documentary database and, above all, of more systematic and in-depth investigations into the buildings, aiming to define and quantify the different types of tying in relation to the type of building, the period of use, and the structural function (link between parts or contrast of the thrusts, original contribution or subsequent reinforcement).

Richer and more continuous documentary series could help to build a chrono-typology of the ties and to identify the chronology of possible changes (in the productive and commercial chain, in the mentality, etc.), thanks to both explicit and implicit references (first appearance of new words or expressions).

Many issues can only be fully addressed by experts from other disciplines, as exemplified below.

a. Information on iron production deducible from accounting records, inventories, or testimonies relating to ironworks document the adoption of two types of iron reduction (direct, definitely more widespread, and indirect methods) and different starting materials (iron ore only or ore mixed with cast iron or scraps). Through the chemical analysis of the inclusions present in the objects and the appropriate investigation protocols (Dillmann et al. 2015) it is possible to recognize the smelting processes used to produce iron (Disser et al. 2014, Dillmann and L'Héritier 2007) and its origin (Benvenuti et al. 2016, Disser et al. 2016, L'Héritier et al. 2016). It would be interesting to ascertain, through metallographic investigations on the elements in place, whether the clear picture provided by the documentary sources is valid or not. Studies carried out in other territorial realities have in fact shown how the archeometric approach can add data that is complementary and unexpected with respect to that coming from archives, contributing significantly to the history of techniques (Dillmann and L'Héritier 2016).
b. The comparison between the prescriptions of the Genoese construction specifications and the opinions on metal ties expressed in the contemporary treatises highlights a certain divergence: while clients and builders seem to place their maximum trust in them, architects

and theorists such as Vignola, Scamozzi, and, above all, Milizia, between the 16th and 18th centuries, criticize them or even refuse them, both for reasons of architectural and constructive purity, and for the dangerous phenomena of degradation and thermal expansion that they could incur (Vecchiattini 2019). Starting from the famous case of the Duomo of Milan, and even outside Italy, conflicting opinions alternate, according to which the use of iron with structural function is from time to time suggested or rejected (L'Héritier et al. 2012, 557–558).

In Genoa ties with diagonal braces were widely used in 17th-century constructions, which demonstrates that the practical experience of the builders of that era had not highlighted significant defects in them. Carlo Francesco Dotti (1730), a Bolognese architect, harshly criticises the use of such ties which he calls "*a braga*" ("branched") and, right from the title page of his booklet, warns that this argument is not sufficient to deem them viable. Many secular buildings with "branched" ties still exist and show no signs of distress. What can today's structural engineers tell us about this, in the light of current scientific knowledge? Are they a useless tool, as Valadier (1828–1839, IV, 92) claims and as suggested by the finite element model of the vault with branched ties of Santa Maria delle Grazie la Nuova (Boato, Lagomarsino, and Pittaluga 2003) or, in fact, potentially dangerous, as stated by Dotti? If so, under what conditions?

c. The documentation examined has not yet highlighted the use of practices, considered traditional, involving putting the ties under traction through heating before fastening them with the relative anchors (Coïsson 2012). The study of existing buildings suggests that any initial traction could have been achieved through simple forcing of the anchor with a variable section into the "eye" of the tie. Is it possible to quantify the extent of the traction that could have been conferred to the tie in this way? In what situations, among those mentioned in the contracts and taking into account the construction situation in Genoa, would it have been useful for the ties to be under tension at the time of their installation?

The question of the actual structural role of these metallic elements is not just about the history of technology or the history of ideas. The safety of the historical buildings in which they are used is also at stake: in order to correctly determine the static and dynamic functioning of structures reinforced with metal ties, it is necessary to know the role and mechanical behavior of these reinforcements, which are the focus of some recent research (see the articles of this special issue). For reasons of space, I shall confine myself mentioning the multidisciplinary studies currently under way in Genoa at the behest of my colleague Chiara Calderini (Calderini et al. 2016), to whom I hope my investigations will make a useful contribution.

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