Iron reinforcements in the medieval and modern attics of Belgium

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Introduction

Over the past few years, research on iron in European building heritage has increased. The problematic approached from the historical, archaeological and archaeometric angles has become a focus of interdisciplinary studies whose objectives concern both architecture and the history of techniques [1][2][3]. Currently, it is accepted that iron has an important place as material used in medieval and modern buildings. Nevertheless, studies focused mainly on wrought iron used in masonry and stained-glass. Its utilization in carpentry has only been observed on certain occasions.

This research context combining iron and wood has however an extraordinary advantage, which is the possibility to study metal with chronological accuracy, thanks to dendrochronology, a dating technique of the felling of the trees to the exact year [4]. Assuming wood was used "fresh", that is quickly after the tree was cut, the date of its felling directly yields the date of the carpentry in which it is used, and therefore indirectly the date of the metal elements related to it.

In the last ten years, the systematic study and dating of iron in carpentry in Belgium (in particular in Wallonia) allows the observation of the use of this material in attics on a large spatio-temporal scale. The census of metallic artifacts in their original environments enables us to progressively build a typochronological inventory. This inventory began in 2009 as part of a doctoral research (carried out at the European Centre of Archaeometry of the University of Liège, Belgium) [5-6]. It continues since 2015 with an observation mainly focused on the Brussels-Capital Region (thanks to funding from the *Direction des Monuments et des Sites* of the *Service public régional de Bruxelles*). The inventory now includes more than a thousand iron reinforcements dated between the 12th and the 19th centuries [7]. Such a collection of data can directly be used to understand the evolutionary process of the use and practice of reinforcements in attics and for reflection about the major steps of their morphological evolutions. U-shape bracket, iron strip or iron tie rod, funnel-shape or bent end, fixed by a staple or iron dowel: these are all features to focus on as they can be related to a specific period and/or region.

The first iron occurrences in Belgian timber frames appeared in the course of the thirteenth century. This emergence of the use of reinforcement has been linked to the change from the compressive framing system with column, to the triangulated system with kingpost and the increase in roof heights and slopes [8]. Following this process, the technique thrived with a phase of assimilation and development until the seventeenth century inclusive. Indirectly, it is possible that the decrease in the supply of lumber may have influenced the increase in the quantity of metal pieces used in timber frames [9]. From the eighteenth century onwards, the use of iron in timber frames experienced an intense boom. This increase was linked both to the systematization of knowledge acquired and to the multiplication of uses.

The main usages

Iron could be used in a variety of places in an attic framework: as a means of fastening, reinforcing or repairing armature. Depending on cases, certain types of armatures were preferred to others.

When carpentry was strengthened with iron reinforcements, these were most often located at the junction between the tie beam and the kingpost: node of strong tensions between the tie beam which bends under its weight and the kingpost which pulls it towards the ridge. Various systems were then implemented to reinforce this junction. These may be wooden reinforcements such as the one described by Eugène Viollet-le-Duc [10] (Fig. 1a). Occasionally, the mortise and tenon joint was simply secured by iron pins. More often, the reinforcement at the junction between the tie beam and the kingpost was more developed and consists of an iron armature such as a U-shape bracket or an iron strip.

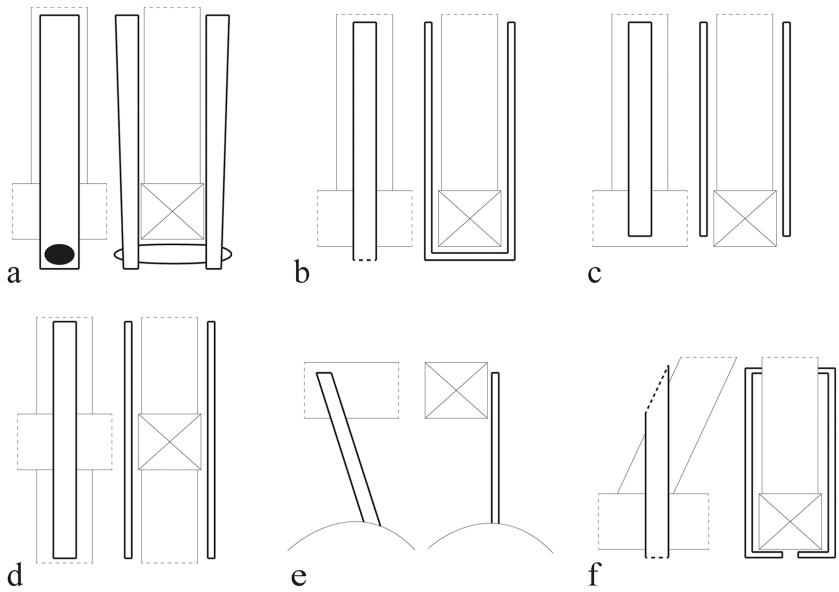

Figure 1. Schematic representation of the most common uses of iron or wooden reinforcements in timber frames in Belgium. Drawing: Christophe Maggi.

The U-shape bracket

The U-shape bracket (Fig. 1b) was an iron strip bent in two points to pass under the tie beam and to enclose the kingpost on both sides. Its use was widespread between the thirteenth and nineteenth centuries in Belgium and elsewhere, notably in Germany [11] and Italy [12]. However, the use of the U-shape bracket decreased in Belgium from the sixteenth century onwards.

This armature could be applied in different ways and fixed to the wood in various means: nails, iron dowels or staples. It could be placed without any particular arrangement (Fig. 2a) on a wooden plank to cover the difference in thickness between the two pieces of wood it joins together (Fig. 2b). The U-shape bracket could also be bent to

fit the wood over its entire surface (Fig. 2c). For the same purpose, the thicker wood that the U-shape bracket reinforces could be hollowed out (Fig. 2d). The last example 'German-style' is not referred to in Belgium. It is only known through two German architectural treatises [13][14]. In this model, the two arms of the U-shape bracket were applied on one of the side faces of the kingpost (Fig. 2e).

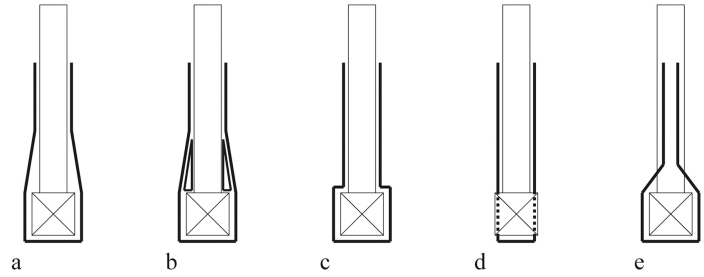

Figure 2. Schematic representation of the different applications of U-shape bracket at the junction between a tie beam and a kingpost. Drawing: Christophe Maggi.

The use of the U-shape bracket has been described by many architectural theorists, some of whom did not hesitate to recommend its use [15]. Throughout the treaties, various terms were used for this type of reinforcement: *estrier*, *étiran* or *bride*. The latter term, used in the nineteenth century by J. Stork [16], refers to a U-shape bracket closed in its upper part by an iron strip giving the whole an O shape. This element is characteristic of modern restoration of carpentry.

The iron strip

The iron strip is a very general term that includes a wide variety of reinforcement characterized by the fact that it is a flat iron strip bent in one point or not. Like the U-shape bracket, the iron strip has been very much used: also at the junction between the tie beam and the kingpost (Fig. 1c) or between the collar beam and the kingpost (Fig. 1d), if the latter is made up of several sections. The use of the iron strip has crossed all eras from the thirteenth to the nineteenth century. However, it was not until the sixteenth century that these elements became the main reinforcement of timber frames instead of the U-shape bracket that had dominated until then.

The means of fastening were the same as those for the U-shape brackets: nails, iron dowels or staples. There were also several ways to place them. The iron strip could be affixed to the pieces of wood it joins together without any particular arrangement (Figs 3a-3b). The piece could also be bent to fit the wood over its entire surface (Fig. 3c). Or the thicker wood could also be hollowed out (Fig.3d). In the above cases, the iron strip is called 'applied' because it is plated on the tie beam. But the iron strip can also be 'traversing' when it is inserted in the beam (Fig. 3e). Its lower end then takes the shape of a dowel. The traversing disposition was mainly used until the fifteenth and sixteenth centuries, after which it was gradually supplanted by the applied disposition. Whatever the configuration, an iron strip could be doubled by a second one, set up in parallel on the opposite side of the beam.

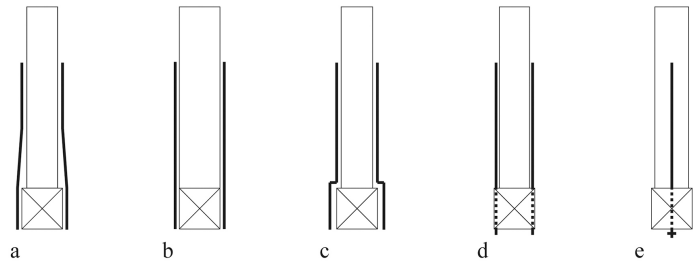

Figure 3. Schematic representation of the different applications of iron strip at the junction between a tie beam and a kingpost. Drawing: Christophe Maggi.

This type of reinforcement was used as much as the U-shape bracket and was similarly recommended by some ancient architectural theorists. Because this category includes a wide variety of armatures, many terms were used in the treatises according to the shape or role of the armature: *harpon* and *frète* (most common) ; *croc* (some sort of big staple) ; *boulon* (refers to the dowel shape of the lower end of the traversing iron strip).

The iron tie rod

The family of tie rods is very different from the first two. Unlike U-shape brackets and iron strips, tie rods do not generally contribute to the consolidation of the carpentry. Tie rods are attached to the carpentry but to serve the masonry by relieving the vaults or preventing the walls from spreading apart (Fig. 1e). The tie rod is therefore often linked to different materials: stone, brick or even cob.

Among tie rods, a distinction is made between those in the shape of a flat iron strip and those corresponding more to a very large thick bar. The first ones, used around the fourteenth and fifteenth centuries, were placed at the junction between the top of the bearing wall and the carpentry. They joined the two together via the ends of the tie beams or the wall plates. Their main function was to prevent the walls from spreading apart. The second diagonally connected the centre of the tie beams to the bearing walls or buttresses, sometimes crossing the vaults (Fig. 4). In Belgium, this type of tie rod only appeared during the sixteenth century, mainly in Brussels (e.g. *Notre-Dame du Sablon*), before spreading to other regions. Its use then rapidly expanded. In the course of the eighteenth and nineteenth centuries, several old vaulted attics were restored, and new tie rods were installed.

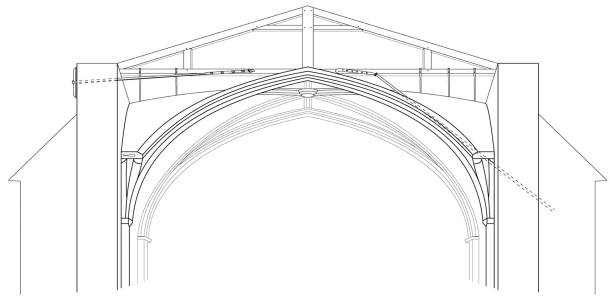

Figure 4. Examples of various possible arrangements for iron tie rods in an attic. Drawing: Christophe Maggi.

This vault support system allows, among other things, reduction of the thickness of the buttresses. In Italian renaissance architecture, this system has therefore played a key role. This is why iron tie rods are found in the attics of Italian buildings as early as the fourteenth and fifteenth centuries, particularly in the cathedrals of Siena and Florence [17].

Other reinforcements

The connections between tie beams and rafters were often consolidated by iron reinforcements, the arrangement of which varied. When these armatures were U-shape brackets, they were usually arranged from the top of the truss and oriented downward so as to encircle the rafter (Fig. 1f). In the same situation, iron strips were installed on the lateral or upper sides of the rafters. Jacques-Raymond Lucotte illustrated, in the *Encyclopedia* [18], the second way of which very similar models were used in the timber frame of the attic of the Saint-Joseph church in Namur (Fig. 5).

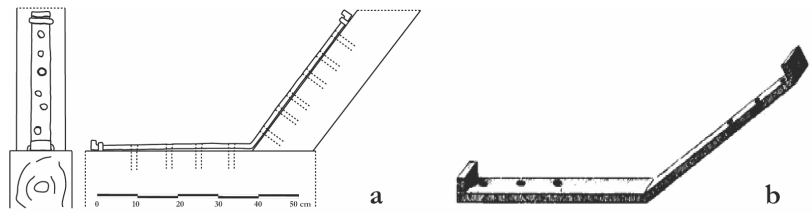

Figure 5. a. Iron strip set between the rafters and the tie beams in the timber frame of the Saint-Joseph church in Namur (1662); b. Illustrated model from the Encyclopedia, 1751.

The main shapes

Several morphologies recur repeatedly throughout the whole range of reinforcements. The shape of a reinforcement derives from its initial appearance, which is approximately equivalent to a quadrangular iron bar, sometimes flattened. It is shaped on the one hand to give the reinforcement a function (e.g. a U-shape bracket, iron strip or a tie rod) and on the other hand to provide it with the means to fulfil this function: flares, protrusions or dowel holes, *etc*. This shaping concerns the metal piece as a whole or in part.

Among these forms, a distinction must be made between the active form (that helps the armature fulfill its role) and the passive or decorative form (whose only purpose is aesthetic). Through these two categories, there are forms that make a good chronological marker and others that can be found everywhere and throughout time. In the latter case, rectilinear reinforcements, that do not have a particular shape (four straight edges), are a poor marker.

The most frequently recurring end forms in Belgian attics are funnel-shape, bent end and doweled. The fin shape, associated with the body of the reinforcements rather than at the ends, is also common.

The funnel-shape

The funnel-shape mainly concerns the end of the reinforcements (Fig. 6a). The body of the reinforcement in this case keeps its original appearance of a flattened iron bar. However, sometimes this shape extends from one end to the other. The whole piece then takes on the appearance of a funnel. This shape is designed to allow more nails to be placed at the end of the reinforcement (often arranged in a triangle) or a staple under the flare.

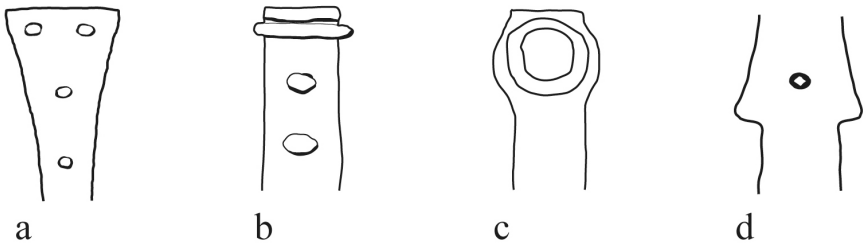

Figure 6. Schematic representation of the most common shapes of reinforcements in timberframes in Belgium. Drawing: Christophe Maggi.

This typology was frequently used in Belgium between the thirteenth and sixteenth centuries. From the seventeenth century onwards, the frequency of use diminished and then stopped. The funnel-shape is the most recurrent typology during the late Middle Ages and the Renaissance in Belgium. However, no treatise describes or illustrates an armature characterized by this morphology.

Elsewhere, this typology is regularly encountered as well. In Germany for example, the attic of St. Peter's Church in Eisenberg contains funnel-shape end armatures dating from 1584-85 [19]. In France, in Champagne-Ardenne, a drawing by Friedrich Ostendorf also testifies to the presence of this end morphology around the fourteenth and fifteenth centuries [20].

The bent end

The ‘bent end’ is the result of the bending of the end of the reinforcement to form a protrusion. (Fig. 6b). Depending on the arrangement, this protrusion can be turned towards the wood into which it is then driven. Otherwise, the protrusion is turned into the position opposite the wood and a staple is inserted over it. The protrusion has a different aspect depending on the fold done. A distinction is made between flat protrusion (90° fold) and thick protrusion (180° fold). Although the first case is more frequently encountered, both are present during the same periods.

The first examples of the ‘bent end’ date back to the fourteenth century. However, it was between the sixteenth and nineteenth centuries that this form was most commonly used.

The bent end morphology is well documented in Belgium as well as in France, Germany and Italy. It is also mentioned in old treatises. Already in the fifteenth century, Leon Battista Alberti mentions *harpons* used in the

field of masonry [21]. These *harpons*, comparable to large staples, are flat iron strips whose two bent ends are embedded in the stone. In his article on locksmithing, Jacques-Raymond Lucotte illustrates these same *harpons* applied to the field of carpentry. He describes them as *des barres de fer méplates […] portant un talon à chacune de leurs extrémités, pour être entaillées dans le bois et attachées de clous […] Cette pièce sert à unir deux poutres ou pièces de bois* [22]. Subsequently, many theorists use the term *harpon* to refer to these same iron strips with bent ends.

The doweled shape is mainly applied to the ends of the reinforcement, but it can also be found sometimes on the body. It is due to the arrangement of a dowel which influences the shape of the armature with a widening (Fig. 6c). Beyond the doweled widening, the end can be straight, rounded or bent.

The ‘doweled end’ emerged in the sixteenth century and was subsequently intensively used. In their 1861 treatise on carpentry, V. Biston and P.-A. Hanus describe and illustrate U-shape brackets attached by one or more dowels which, placed at the ends, form a rounded widening [23]. Previously in 1650, Mathurin Jousse already proposed the use of U-shape brackets fixed by dowels to support the tie beams [24].

The ‘doweled end’ can be seen in other regions than Belgium. In Halle, Germany, the choir timber frame of St. Ulrich's Church (built in 1670-71) is reinforced in several places by U-shape brackets with doweled ends [25]. The same type of U-shape bracket is used in the timber frame of the cathedral of Beauvais, France, to relieve a tie beam that has suffered repetitive structural accidents. In England, the morphology of doweled end is also recorded. It can notably be seen in the attic of the nave of Winchester Cathedral, whose construction dates back to the end of the seventeenth century [26]. The doweled end of the reinforcements is still present in Italy, where the type can be seen in the attic of the Church of All Saints in Florence, whose timber frame dates back to the eighteenth century [27].

The fin shape

This morphology is specific to the body of the armatures (Fig. 6d). There may be only one pair of fins on the whole body or the pattern may be repeated several times. The flares, that these fins establish, allow a staple to be slipped into them to hold the metal piece in place. These fins are made only on U-shape brackets or iron strip (not on iron tie rod). The use of this form takes place between the fourteenth and sixteenth centuries. The shape disappears afterwards.

This morphology is strongly present in Belgium. On the other hand, its echo seems to be more tenuous in the timber frames of bordering regions or in the treatises.

The fin shape has not always been the same: symmetrical, flattened or stylized (Fig. 8). It has evolved over time, like other morphologies, according to the development of tools and changes in shaping methods.

The shaping of the armatures

The iron reinforcements used in timber frames are only products from the forge. No cases of cast iron have been recorded. The forge was in two steps [28]: firstly, the general manufacture of the armature (U-shape bracket, iron strip or iron tie rod), then the execution of the finishing forms (flares, protrusions, dowel holes, *etc*.).

Most of the work was done in the workshop but some retouching could be done on site for final adjustments. This is the case with nail holes, for example. They could be pierced hot or cold (if the piece was thin enough). In theory, it was advisable to prepare the item to be pierced on the two opposite sides with a punch in order to avoid burrs [29]. In practice, it seems that this technique was not respected when forging the armatures. Actually, many have crushed bulges on the side towards which the iron was driven, that means the one opposite to the penetration of the punch. The possibly banal consideration of the armatures is perhaps the reason why their realization did not necessarily deserve specific care. Once the hole was punched, it was gradually enlarged with thicker punches or with a mandrel [30].

For example, larger holes in the reinforcements in which to insert iron dowels could also be made using punches or chisels. The resulting slot was then gradually widened until it formed a gap that could accommodate an iron dowel. In the end, the hole was never really circular, and its widening created a flare of iron that was transmitted to the edges of the armature (Fig. 7a). In the case of a doweled end, it could be forged separately. A small bar was folded back on itself, leaving a central hole for the insertion of the iron dowel. The shape was then added and welded to the end of the armature (Fig. 7b).

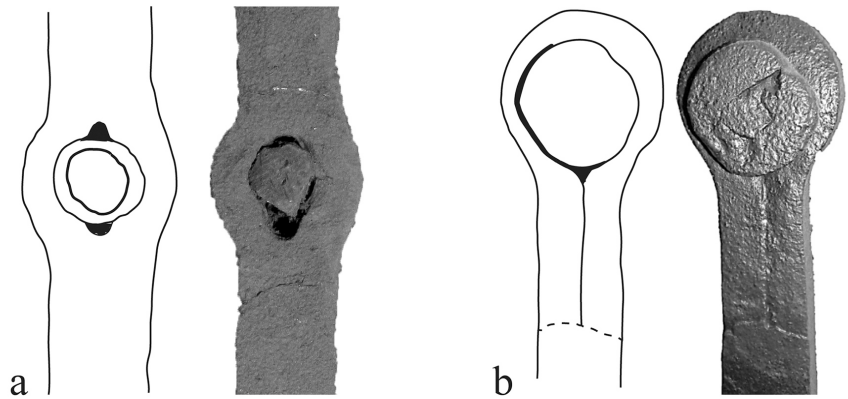

Figure 7. Schematic representation of two forging techniques to obtain a hole for inserting a iron dowel. Drawing: Christophe Maggi.

Flares such as fins were mainly obtained by forging the side faces of the reinforcements. In this way, the fins were gradually released from the frame while the width of the other sections was reduced, and the room was lengthened (Fig. 8a). The funnel shape was elaborated in the same way. During the sixteenth century, in the last periods of the use of funnel and fin shapes, two other ways of executing these flares appeared. Starting from a straight strip of iron whose length, width and thickness were already at the right dimensions, the blacksmith hammered the lower and upper sides on the periphery of the armature. The iron then expanded, causing the formation of fins with a flattened profile (Fig. 8b). Another way of doing this, always starting from a pre-established iron strip, was to cut the edges of the reinforcement and stretch them towards the outside of the frame. (Fig. 8c). A slight constriction was then visible under the protrusions formed by the fins.

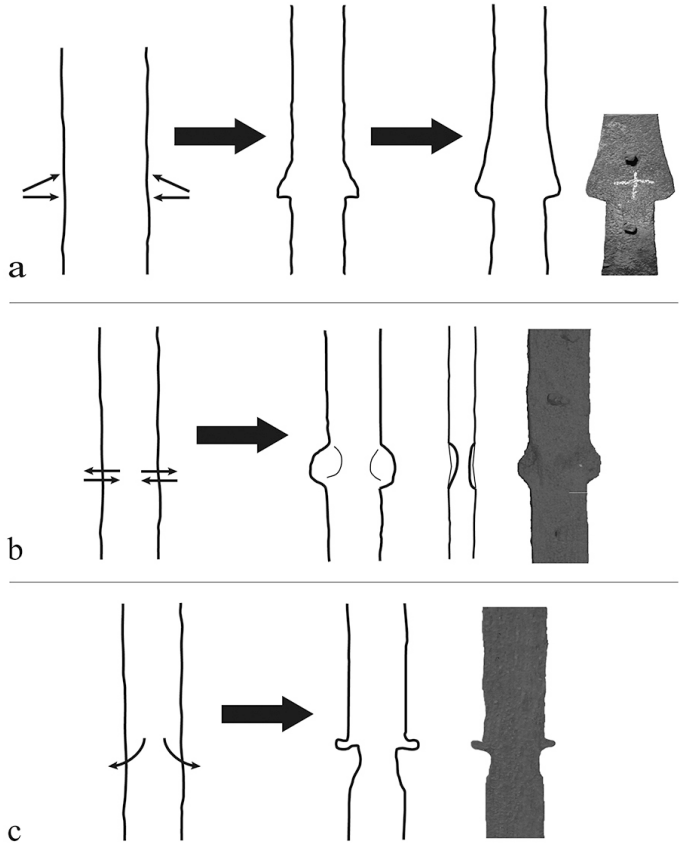

Figure 8. Schematic representation of tree forging techniques to obtain the fin shape on an iron armature. Drawing: Christophe Maggi.

As can be seen by observing the uses and forms of the armatures, an important change took place around the sixteenth century. Some types or forms of reinforcement are disappearing or are less used while others are increasing (Fig. 9):

- transition from U-shape bracket to iron strip;

- transition from traversing iron strip to applied iron strip;

- transition from fin and funnel shapes to bent or doweled ends.

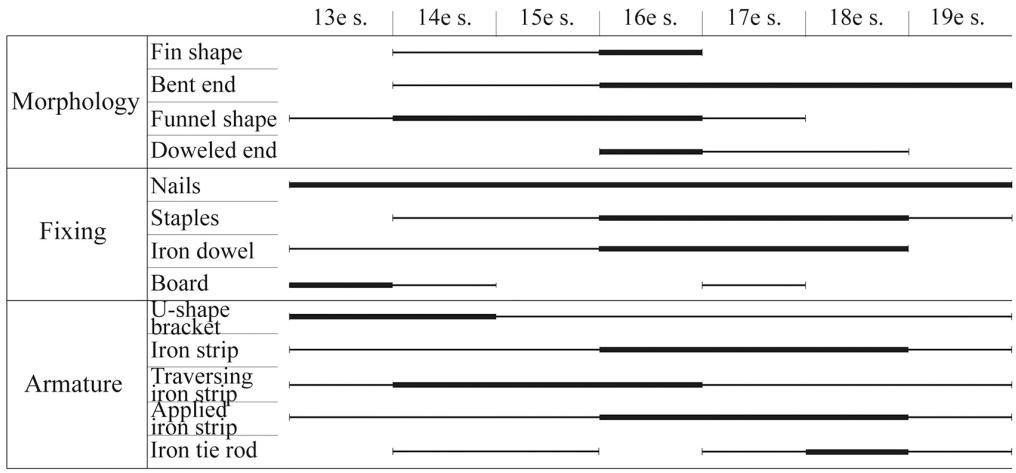

Figure 9. Time lines summarizing the evolution of the types of reinforcement, their morphology and means of fixation. Drawing: Christophe Maggi.

This change is mainly the consequence of a transformation of the chain of operations linked to the development of machinery (*platinerie*, *fenderie*, *tréfilerie*, *clouterie*, *etc*.) and progress in mechanization. In timber frame, the first iron reinforcements that seem to have come out of this type of workshop date back to the sixteenth century. However, the development of these machines does not directly mean that all reinforcements were made from them at that time. Assimilation has been gradual.

Conclusion

The development of the workshops has made it possible to manufacture semi-finished products that only need to be transformed into finished products. A change in forging work then took place, the effect of which had repercussions on the morphologies. This was observed in carpentry as early as the sixteenth century and was clearly confirmed in the eighteenth century when Augustin-Charles D'Aviler, in his *Cours d'architecture*, advised the workers that the '*gros fers*', like iron tie rods, should be forged only in their ends without modifying their thickness and that the rest should be left '*comme il est livré par les marchands*' so as not to weaken it [31]. If, from the sixteenth century onwards, fin or funnel shapes have disappeared, it is because the shaping processes have changed. The piece arrived at the forge in a semi-finished state. It only remained for the blacksmith to adapt it to its function in particular by making the fastening system. Thus, in the course of the sixteenth century, various processes, such as pressing or cutting, were tested to shape fins, without having to retouch the body of the armature. Thereafter, the shape was gradually abandoned. On the other hand, in the same period, the bent end has become the most widely used form. Its manufacture was simple, fast and efficient, and it did not alter the dimensions of the original iron reinforcement. Also from the sixteenth century onwards, the reversal of supremacy between the traversing iron strip, requiring a lower forged dowel-shaped end, the applied iron strip with two identical ends, can be attributed to the progress of mechanization which, in its own way, influenced the functioning of the chain of operations.

Without becoming an essential material for timber frames, the use of iron has continued to grow over time. Initially placed at joints that were subjected to tensile stress, reinforcements spread into the attic space and were used to reinforce all types of arrangements. In the nineteenth century, the use of iron armatures in carpentry exploded in conjunction with the Industrial Revolution. Functions and interest of iron have thus evolved little by little. Beyond the protection it embodied for wooden structures and masonry, iron gained its independence by holding its own place in architecture for the first time. It detached itself from the materials that constrained it to a secondary role and was deployed in isolation. This initiative will go down in architectural history as the prelude to a process that will finally lead to the first all-metal frameworks.

The importance of iron in timber frames is therefore great and its history is rich in lessons learned. Research on metal attic reinforcement provides thus a major interest in the general study of timber frames, in line with those on typologies, dendrology or tool marks.

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