From construction to maintenance. The history of the wooden chain encircling the dome of Santa Maria del Fiore

Sofia Celli and Federica Ottoni
Department of Engineering and Architecture, Università di Parma, Italy

Introduction

While most features of the dome of Santa Maria del Fiore have been thoroughly analyzed over the centuries, little attention has so far been paid to the wooden ring encircling it, hidden between the two masonry shells. Indeed, the so called "chestnut chain" was never quite considered, if not as a collateral topic in the long-lasting debate concerning the dome's stability [1]. The present research thus had the aim to increase the knowledge of this device by retracing its construction history.

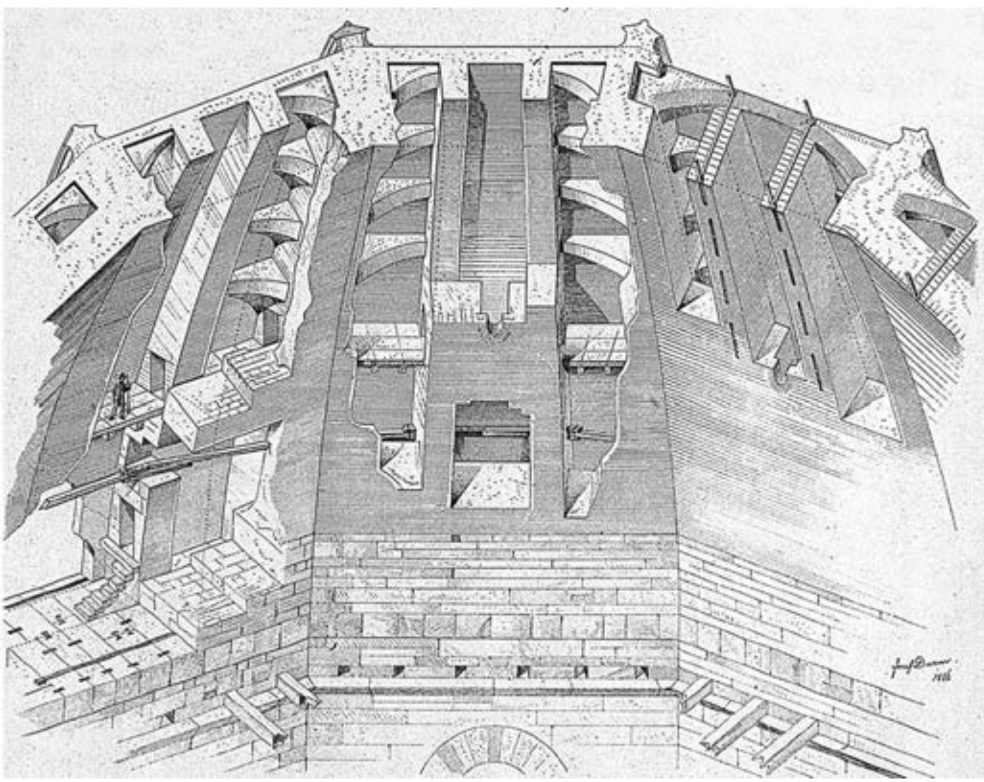


Figure 1: The structural arrangement of Brunelleschi's dome with the one built wooden ring in Joseph Durm's representation (1887) [2].

The wooden chain was already included in the 1420 cupola programme [3], as a part of the elaborate encircling system that was supposedly studied by the designers to contrast the (empirically acknowledged) outward thrusts of the masonry dome, thus preventing its typical collapse mechanism. Such system comprised several typologies of tie-rods, including stone, iron and wooden rings. In particular, the wooden chains were initially meant to be four (one every 12 braccia, or 7 metres in height), but in the end, due to subsequent changes to the original plan [4], only one of them was actually realised (Fig. 1).

The resulting chain was built between 1423 and 1424, according to Brunelleschi's design, as confirmed by several archival documents [5].

Since its construction, the wooden ring has undergone several transformations owed to maintenance interventions and, most likely, repairs following periods of neglect or traumatic events (e.g. earthquakes and lightening). In particular, the archival documents indicate water as the main cause of damage, highlighting a strict correlation between filtrations from the dome's cracks and wooden rotting [6].

Through this process, the artefact slowly came to acquire its current configuration and, most importantly, was preserved and kept "intact" until current days, which was far from predictable, especially given the intrinsic perishability of wood. Moreover, the slim number of similar devices to be found nowadays increases its value and importance as a nearly unique evidence of a specific technology and its evolution in time. As a matter of fact, the substituted and added metallic joints that can be seen on the wooden ring testify to the progress of craftsmanship, with particular reference to ironmongery and timber joints.

For these (and yet other) reasons, it seemed opportune to begin the study herein summarised.

The state of the art

As aforementioned, literature focusing specifically on the wooden chain is rather scarce. The few scholars who addressed this topic mostly dwelled on its structural role (or lack thereof) [7]. Such assessments were largely made based on general considerations, such as the features of the building material, the position of the device, the ease of maintenance and so forth, without ever truly providing a systematic analysis of the artefact. Historically, the most relevant study of the wooden chain can be attributed to Giovan Battista Nelli, who, in 1695, performed a thorough survey of the wooden ring in order to verify its state of repair and functioning.

At the time, due to a quick worsening of the cracks of the cathedral's dome – possibly caused by an earthquake that occurred in the September of the same year [8] – the Florentine community was deeply concerned about the future of the structure. A committee, which included Nelli, was nominated to examine the situation and establish whether it was advisable to add a set of four hooping iron tie-rods to prevent the collapse of the building [9]. To that end, the committee gathered information on the wooden chain, both directly investigating the device and seeking suggestions from other fabric surveyors, such as those of the St. Peter's Basilica in Rome [10]. However, since the latter had never had any wooden rings, the most knowledge came from on-site observations. Nelli provides us with relevant data concerning both the state of repair of the chain – which, at the time, was rather poor [11] –, and with an approximate representation of the joints connecting the 24 beams [12] (Fig. 2).

Although not completely consistent with the reality, Nelli's drawing became the most reliable source for most of the scholars who later dealt with the topic. While adding a few details, Rondelet [13], Durm [14], Prager and Scaglia [15], and Ricci [16] all portrayed the wooden chain basing on Nelli's work, without ever rectifying its inaccuracies. As a matter of fact, given that a part of the joints is hidden within the spurs' thickness, their true arrangement is still unclear, although definitely different from the suggested hypothesis. Moreover, the existing illustrations of the wooden chain only focus on one type of joint (seemingly the original one), and miss taking into account all the subsequent solutions resulted from maintenance and repairs.

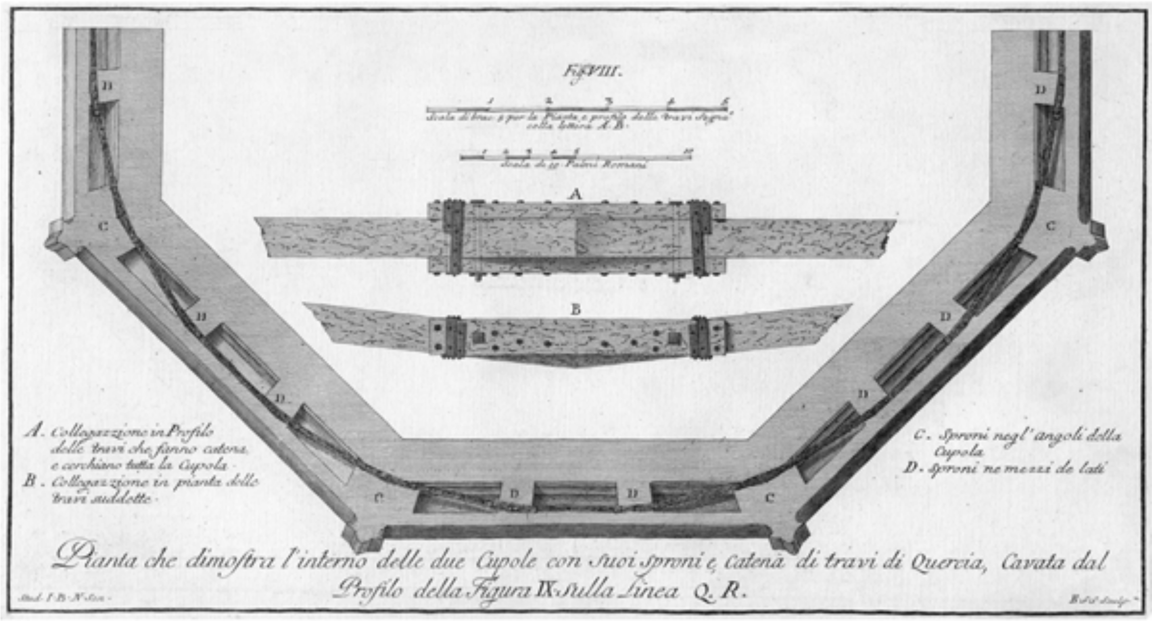


Figure 2: The joints of the chestnut chain according to Nelli's survey (1733) [17].

Beside the drawings of the chestnut ring produced over time, in the last fifty years there have been a few studies aiming at analysing the construction of this peculiar device [18]. While successfully discovering archival papers from the Fifteenth Century, the above studies did not make any attempt to correlate the historical data with the physical artefact in its current state. Later additions and maintenance interventions were not considered at that time either.

Renewed interest in the chestnut chain arose on the occasion of the celebrations for the six hundred years from the beginning of the dome construction (1420-2020). In view of the event the Opera di Santa Maria del Fiore fostered new studies, among which an archival research to investigate the history of the wooden ring and a laser scanner survey [19] to finally obtain a highly detailed representation of its geometry and dimensions. These two tools, in addition to the on-site observations, laid the basis for the integrated process that led to the dating of most of the metallic joints of the chain in question.

Method

As usual, the research started from the literature analysis, with particular reference to the collection of documents published by Cesare Guasti [15], and the digital archive of the sources of the Opera edited by Margaret Haines [20]. After isolating some significant dates - mostly related to catastrophic events such as earthquakes and lightening - the study resorted to the historical documents stored in the Opera's archive, shedding light on long-lost pieces of information spanning several centuries. A first reading of the documents allowed the acquisition of general knowledge about the way the wooden chain was perceived throughout time and how such a perception reflected on maintenance activities.

The complete understanding of the newly found data was however only achieved by comparing the historical information with the artefact in its present state, as well as with the accurate geometric survey that was recently performed. In fact, while rather detailed, the architects' annual reports, and the blacksmiths' and carpenters' expense records rarely offer spatial references. Thus, the mere analysis of archival documents would not have enabled the accurate location of the maintenance interventions described along the wooden ring. By combining the information collected from the historical documents with that deduced from direct observation, it was possible to make up for the lack of spatial data.

Operationally, the first step was to identify, examine and classify the different kinds of metallic joints currently existing on the device. Overall, six types were detected, heterogeneously distributed along the wooden beams and tracing back to different epochs (Fig. 3). The comparison between the archival descriptions of the metallic components and the visible elements highlighted quite precise matches, allowing the establishment of a correspondence between the historical documents and the tangible artefact. The most plausible correspondences were subsequently verified through a dimensional crosschecking: the measurements indicated by the expense records, after opportune conversions [21], were compared to the dimensions obtained from laser scanning. While the comparison between linear measurements was quite immediate, weight measurements required a bit more effort. A geometrically regularized 3D model was created for each of the six metallic joints in order to easily obtain the rough volume, and, therefore, the possible weight. Undoubtedly, the approximations that were made – concerning both the geometry of the joints and the density of the iron alloys – entail a mediocre accuracy level. It should however be noted that the purpose of this comparison was not to ascertain a perfect coherence, but rather to verify whether the data could be considered compatible. In fact, even using the highest level of detail, the 3D model might not have provided overlapping results due to material decay, possible reductions in section, and lack of information about the alloy composition.

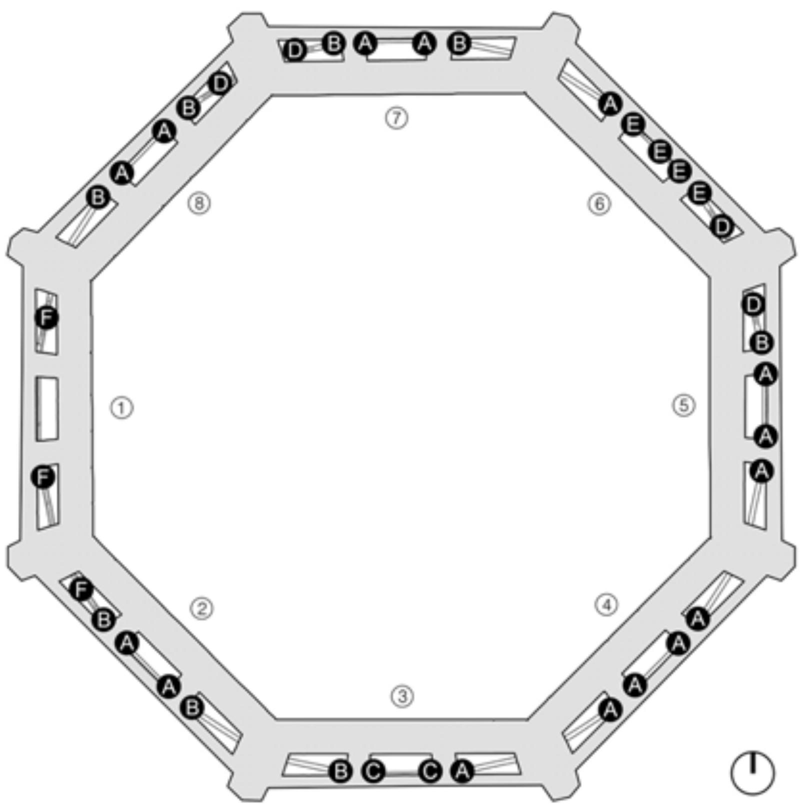


Figure 3: Spatial distribution of the different types of joints along the wooden chain.

Once attested the compatibility between the historical and current dimensions, the dating hypothesis were furtherly validated through the consultation of coeval architectural treaties. In several cases, the latter proved essential to dispel existing doubts regarding the technical systems adopted, as well as to better understand the archival papers' lexicon. Similarly, the close observation of similar case studies of known date offered useful hints to corroborate previous findings.

The metallic joints: an overview

The direct observation of the wooden chain, along with the possibility of accessing the dimensional data of the laser scan survey [22], allowed six different types of joints to be identified. Such joints differ from one another in terms of components, dimensions, workmanship and functioning (Fig. 4).

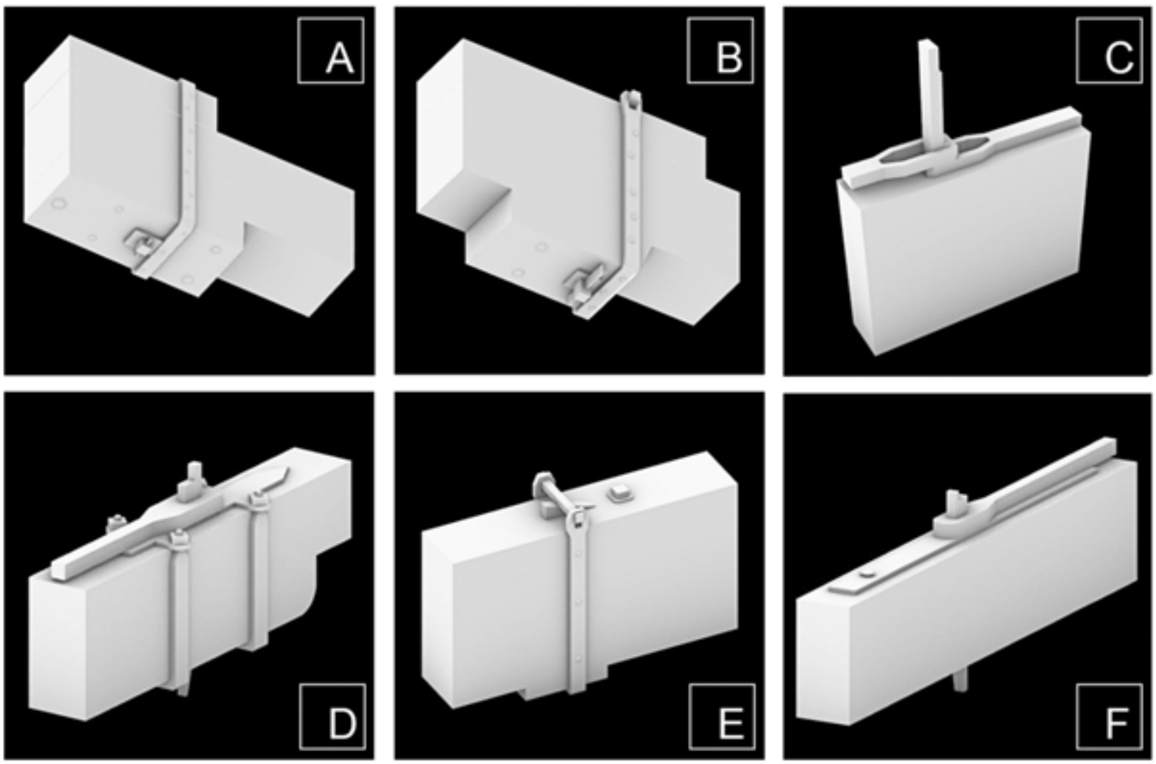


Figure 4: 3D representation of the six typologies of joints identified on the wooden chain.

Each of the six types was examined and catalogued before proceeding to the afore-described cross-checking process. In the end, four types out of six were dated based mostly on the information gathered from the archival research, while the remaining ones, given the lack of documental materials, were dated by comparison with similar case studies and architectural treaties. A brief overview of the joints' configuration is provided in the following subparagraphs.

Type A

The metallic joints named 'A', possibly the original ones (1423-1424), are by far the most common. They appear rather similar to the joints represented by Nelli in 1695 (Fig. 2), as they comprise an iron strap, an iron bolt and several nails (Fig. 4.A). The former is quite thin (1-1.5 cm thick) and is fastened to the beams through a variable number of irregularly disposed nails. The iron bolt has square section (average 3x3 cm) and is blocked on the lower end thanks to a hole and key system. Finally, from two to six plain iron nails were added to further secure the vertical connection. All the metallic elements are visibly hand-crafted.

The components described were used to join together three overlapping wooden elements, namely the main chestnut beam (average section 30x30 cm) and the two "*panchoni di quercia*" [23], which are the oak boards positioned above and below the beam in close proximity to the dome's spurs.

Type B

The joints of the second type are almost completely analogous to those of the first type. The only slight difference can be found in the encircling element: while A-type joints present a simple iron strap wrapped all around the beams, B-type joints have a u-shaped iron strap which closes on the upper end by means of a transversal stake (Fig. 4.B). The latter crosses the thickness of the strap passing through eyelets and gets locked into place thanks to iron wedges.

Other than the iron strap, the components of the joint are identical to the previously described ones as for geometry, dimensions, and manufacturing.

The strict similarity between the two joints led to hypothesise that B-type joints could actually be the result of repairs to the A-type joints. Although further archival researches are required to validate this theory, by considering the craftsmanship of the artefact and comparing it to other case studies [24], it seems plausible that the iron straps were replaced in the Sixteenth century.

Type C

There are only two C-type joints on the chestnut chain, both located within the eighth sector of the dome, on the opposite ends of the beam. Unfortunately, due to the presence of a metallic sheet covering the wooden elements, the joints are only partly visible.

From what can be observed, the joint has a rather simple functioning and it is used to connect the added iron tie-rods both to one another and to the wooden beam (Fig. 4.C). The tie-rods are provided with a loop on both extremities; to join one arm with the next, the loops of adjacent tie-rods are aligned so that a vertical wedge can be inserted to lock them in position. By extending across the underlying beams, the wedge also guarantees the fastening of the metallic tie-rod to the wooden elements.

According to the historical analysis, type C joints can be attributed to the repairs coordinated by Gherardo Silvani in 1637 [25].

Type D

The metallic joints of type D are quite complex and comprise several elements (Fig. 4.D). On the one hand, there is a horizontal connection granted by an additional iron tie-rod located on top of the wooden beam; on the other a double u-shaped strap to vertically fasten the wooden and iron elements. Both the tie-rod and the straps are anchored to two iron plates nailed on the top and bottom surfaces of the beam. The former is blocked by a vertical wedge that passes through the tie-rod's loop and continues downward, transversally crossing the iron plates and the wooden elements. The u-shaped straps, also nailed to the wooden beams, are provided with threaded ends locked by square nuts on the upper part.

Since no archival records regarding this type were found, the installation period (Eighteenth Century) was hypothesized on the basis of architectural treaties and analogies with similar case studies.

Type E

Overall, five E-type joints can be found on the wooden chain, all of which are located in the sixth sector of the dome. Given the presence of one of the most severe cracks of the structure, in this portion the wooden chain has been doubled in section, adding a second wooden beam below the original one. The E-type joints have the role of joining together the two beams.

This kind of joint is composed of two main elements: a u-shaped strap and a bolt, both working vertically (Fig. 4.E). The former is closed on the upper end thanks to an eyelet-stake system, tightened using metallic wedges; the latter has circular section (average Ø 3 cm) and is locked with a square nut on bottom end.

Thanks to the rich archival documentation [26], it was possible to identify 1823 as the installation year. An in-depth description of the dating process will be provided in the next paragraph.

Type F

The last type of joint is the most recent one and dates back to the repairs coordinated by Gaetano Baccani between 1845 and 1848 [27]. It consists of a metallic tie-rod (fastened to the underlying beam thanks to a vertical wedge), and two bolts locked on the bottom end with square nuts (Fig. 4.F). As in type D, the system also includes two iron plates that are nailed to the upper and lower surfaces of the beam to improve the anchoring of the added tie-rod.

The comparative process: dating E-type joints

Once catalogued, each joint type was further analysed and assigned a plausible time of installation. To better explain the comparative process that led to that result, the case of E-type joints will be thoroughly illustrated, as a significant example.

As asserted before, E-type joints were placed on the wooden ring in 1823, at the request of the Opera surveyor Gaetano Baccani. Three very interesting archival documents describe this operation: the carpenter's and blacksmith's expense notes and a report by Architect Baccani [30]. The latter, even though written four years later (1827), provides an essential piece of information: the cause of the repairs. Baccani stated that the wooden ring was found broken at two different points because of the prolonged filtrations of rainwater. Although not univocal, this can be read as a hint to place the described repairs in one of the sectors that show the most severe cracks (four and six). Indeed, the dimensional cross-checking confirmed that the 1823 repairs occurred in sector six.

On the other hand, the expense notes offer detailed descriptions of the wooden and metallic pieces produced by the craftsmen. In particular, the attentive reading of the blacksmith's words allowed one to preliminary match the elements mentioned in the archival paper with those that can currently be observed within sector six. The artisan refers to u-shaped straps whose features resembles the ones in sector six: they have eyelets on the upper ends to insert the closing stake, iron wedges to tighten the straps and, as suggested in the document, they enclose not one, but two overlapping wooden beams (Fig. 5).

The bolts description is rather fitting as well: there are three of them, they are at least partially threaded so that they lock with nuts and have washers both under the head and above the nut. Moreover, the expense note mentions that a square wrench was used to tighten the bolts' nuts, which testifies to the fact that the nuts installed in 1823 were square, just like the existing ones (Fig. 6).

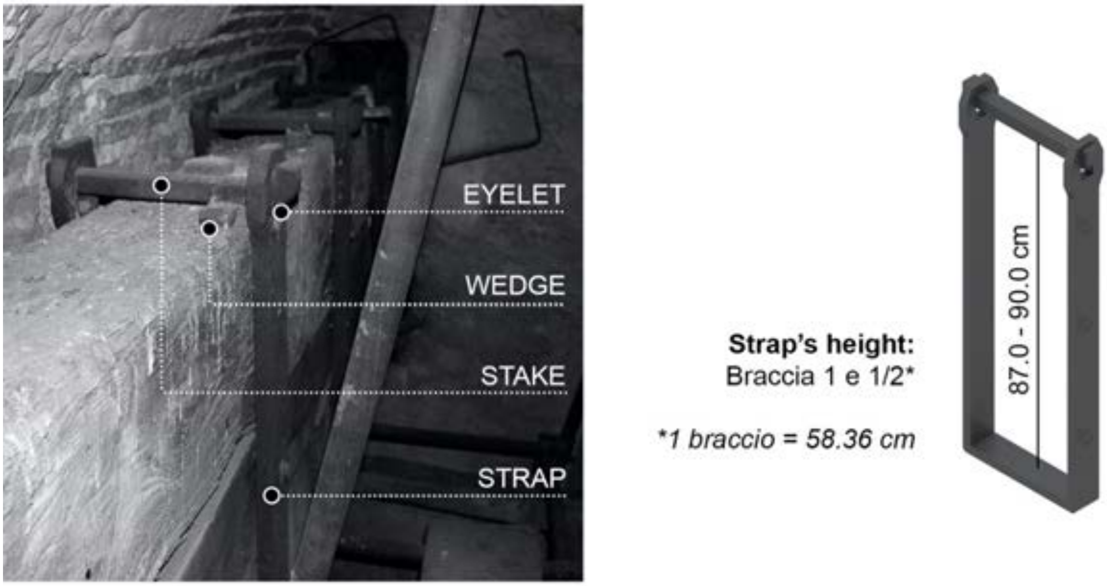


Figure 5: The iron straps of E-type joints and their components. Photo by the authors (2018)

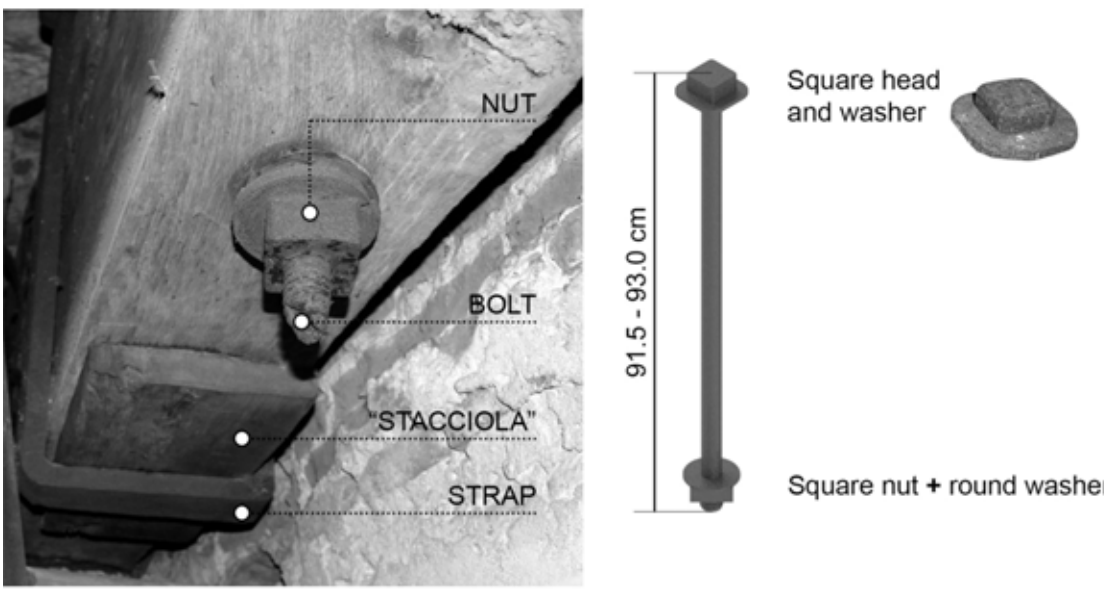


Figure 6: E-type joint seen from below. Notice the lower end of the bolt and the wooden "stacciola". Photo by the authors (2018)

Despite the good level of coherence between the historical document and the built artefact, the note also includes ambiguous information. First of all, the blacksmith affirms to have made 15 u-shaped straps, while today we only see five. We could however assume – as also suggested by a later document [28] – that the missing straps were subsequently removed. Another uncertainty regards the wording "*Colonnone di Legno della Cupola*" ("Big wooden column of the dome") which seems to refer to a vertical element, rather than a horizontal one. Nevertheless, given that the only relevant wooden device within the dome is the chestnut chain, it seemed reasonable to overlook this specific aspect and proceed to the dimensional crosschecking to definitively dispel any residual doubts.

The first dimension recorded by the blacksmith is the height of the u-shaped straps (87.5 cm) which is consistent with the present situation. According to the 2018 laser scan survey, the height range of the metallic straps is from 87 to 90 cm.

The second measure in the note regards an element referred to as "*stacciola*", which is not a very common term in literature and was not found in the main historical Italian vocabularies. It was however recorded by an Eighteenth-century Italian-French dictionary [29], were it is described as a straight edge or square, clearly suggesting the use of the "*stacciola*" as an aid to control orthogonality. Thanks to this new piece of information, it was possible to formulate the hypothesis that the term "*stacciola*" refers to the wooden plank positioned between the bottom surface of the beam and the iron strap (Fig. 6). Indeed, the blacksmith's expense note reports that the "*stacciole*" were 29 cm wide, which is very close to reality since the three existing wooden planks measure 26 to 28 cm. No dimensions are provided with regard to the thickness or length of the planks. The hypothesis was finally validated thanks to Giuseppe Valadier's architectural treatise [30]. When illustrating the possible ways to join two wooden beams together, he mentions the opportunity of positioning a wooden element between the beam and the strap to improve the adherence between them (Fig. 7).

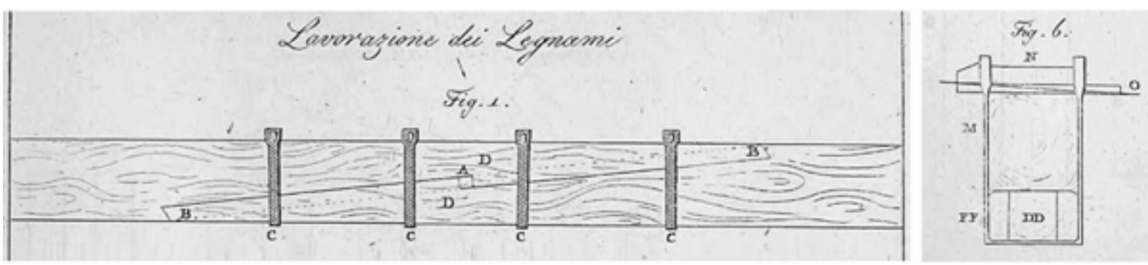


Figure 7: Possible use of U-shaped straps illustrated in Valadier's treatise.. On the right, the mentioned wooden element ("stacciola") to be inserted between the beam and the strap (DD)

After analysing the straps, the cross-checking moved to the bolts, which, according to the blacksmith were three in total. Although the expense note does not provide any dimensions, their description is rather precise and, as previously noted, perfectly fits the current configuration of E-type joints. Once again, architectural manuals offered useful confirmations: among the different types of bolts, Cavalieri San Bertolo (1832) [31] includes threaded bolts, such as the ones described in the archival document.

As usual, due to the fact that metals were priced based on weight, the expense note ends with the overall weight of the listed pieces, which, in the specific case, amounts to 465.311 Kg. In order to check the compatibility of this measurement with the present situation, a rough 3D model of both a u-shaped strap and a bolt was made, considering the average dimensions acquired through laser scanning. The volume of the models was automatically calculated by the software and then multiplied by the density (7.85 g/cm3) to obtain the mass of the analyzed elements. As a result, the average weight of the straps is 30 Kg; that of the bolts is 10 Kg. Finally, the unitary weight values were multiplied by the number of elements produced (that is 15 for the straps and three for the bolts) and finally summed to have the total weight. The result of this calculation is 480 Kg which, given the substantial approximations that were made, can be considered compatible with the historical data.

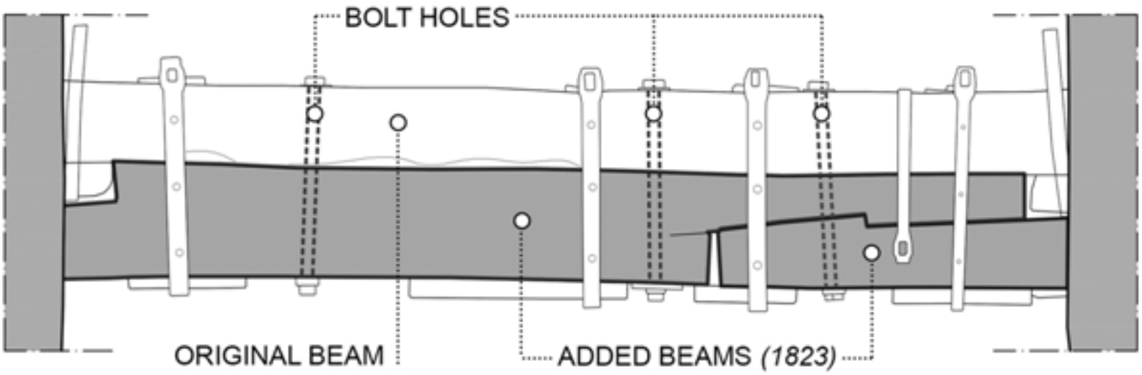
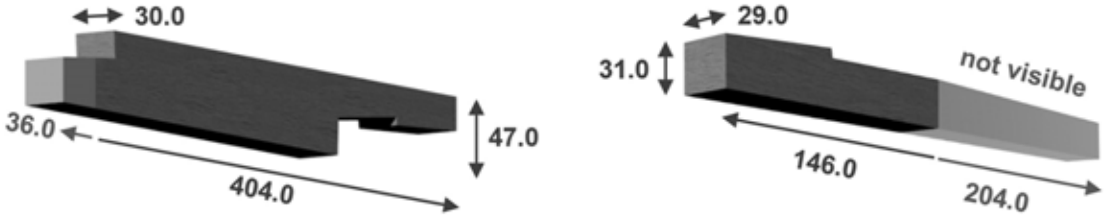


Figure 8: The wooden elements currently existing in the central room of sector six. The darkened beams were supposedly added in 1823.

A few considerations were finally made with regard to the carpenter's work (Fig. 8). In his brief expense note he explains installing two new wooden chains: the first one is 350 cm long, 35 cm tall and 29 cm wide and is said to "stay within the spur". The second one is 440 cm long, 48 cm high and 32 cm wide. The third and last item on the note concerns the three holes the wooden worker had to make in the mentioned beams to fit the iron bolts in. Given that the bolts were installed in the sixth sector of the dome, the best guess was to also find the "new" chains there. Indeed, when observing this portion of the wooden ring, we notice that the beam is actually composed of two overlapping beams: the one on the top appears to be the original one, while the one on the bottom is clearly a later addition. Moreover, the latter is a composed beam itself, as it comprises two different wooden elements connected by a stop-splayed scarf joint. The availability of dimensional data allowed a comparison to be made between the two wooden elements composing the lower, most recent beam and the chains supplied by the carpenter. It should be noted that, since it was not possible to survey the portion of the beams entering the spurs, the cross-checking was only made on the visible part.

Even in this case, the level of compatibility appears to be quite high, especially for the longer segment (Fig. 9 left). Some discrepancies emerged with regard to the smaller beam, which, given the fact that the thickness of the spur is only 150 cm, about 70 cm shorter than the length indicated in the expense note (Fig. 9 right). It is however plausible that the chain was cut during assembling to better fit the designated space.

In the end, considering the overall results of the critical analysis performed, it seems reasonable to assert that the wooden and iron elements added during the repairs occurred in 1823 are the ones located in sector six.



The lighter portion of the beam is not visible. Its lenght was hypothesized basing on the archival data: **4.04** + **36.0** = **4.40** m

1823 expense note	**2018 survey**
Lenght *braccia 7 1/2* = **4.40** m	**4.04** m *(visibile)*
Height *braccia 5/6* = **48** cm	**47** cm
Width *soldi 11* = **32** cm	**30** cm

The length of the portion of beam that is not visible was hypothesized basing on the archival data: **1.46** + **2.04** = **3.50** m

1823 expense note	**2018 survey**
Length *braccia 6* = **3.50** m	**1.46** m *(visible)*
Height *soldi 12* = **35** cm	**31** cm
Width *soldi 10* = **29** cm	**29** cm

Figure 9: 3D model of the two wooden pieces composing sector six's lower beam and comparison between historical and current dimensions.

Conclusions

The systematic application of the described method allowed a dating hypothesis to be formulated for each of the six types of metallic joints. The accuracy of the hypotheses is variable and largely depends on the availability (and nature) of the archival data. Further verifications could be obtained by using specific methods such as dendrochronology and radio-carbon dating. The archival research should also be continued, with particular reference to the least studied centuries (Sixteenth and Eighteenth).

Leaving aside the precision of the results, the study once again underlines the importance of achieving (or at least aiming at) a full integration between the pure historical data and built reality. By intertwining the information collected from the reading of the archival documents with those retrieved from the direct observation of the artefact it was finally possible to retrace the construction and maintenance history of the wooden chain encircling the dome of Santa Maria del Fiore.

Acknowledgments

The research has been possible thanks to the Opera del Duomo di Firenze who promoted the most recent studies concerning the wooden chain. A sincere thanks goes to the Opera's archivists who guided our steps through the archive collection, and to Studio Scaletti and Studio Comes (Prof. Carlo Blasi) who provided the laser scanning of the chain.

References

[1] F. Ottoni, E. Coïsson, C. Blasi, 'The crack pattern in Brunelleschi's dome in Florence. Damage evolution from historical to modern system analysis', Advanced Materials Research, Vols. 133-134, 2010, pp. 53-64.
[2] J. Durm, Die domkuppel in Florenz und die kuppel der Peterskirche in Rom, Berlin: Verlag Von Ernst & Korn, 1887, tav. 43.
[3] Archivio di Stato di Firenze (ASF), Arte della Lana 149, cc. 59v-60r.
[4] Archivio dell'Opera di Santa Maria del Fiore (AOSMF), II.1.80, c. 17v; AOSMF, II.2.1, c. 170v-171.
[5] AOSMF, II.4.9, c. 68; AOSMF, II.1.83, c. 68; AOSMF, II.4.9, c. 67; AOSMF, II.1.83, c. 67.
[6] AOSMF, V.3.19, f. 166; AOSMF, XI.2.5, fasc. 23; AOSMF, XI.8.9.

[7] *Relazione dell'ultima visita del cav. Francesco Fontana* - AOSMF, III.1.9, fasc. 305; C. Nelli, Discorsi di Architettura del senatore Giovan Batista Nelli, Florence: Per gli Eredi Paperini, 1753; L. Ximenes, Del vecchio e nuovo gnomone fiorentino e delle osservazioni astronomiche, fisiche e architettoniche, Florence: Nella Stamperia Imperiale, 1757; F. D. Prager, G. Scaglia, Brunelleschi. Studies of His Technology and Inventions, New York: Dover Publications Inc, 1970; R. J. Mainstone, 'Brunelleschi's Dome of Santa Maria del Fiore and some related structures', Transaction of the Newcomen Society, vol. 42, 1969, pp. 107-126; P. Sanpaolesi, La cupola di Santa Maria del Fiore. Il progetto - la costruzione, Florence: Editrice EDAM, 1977; P.A. Rossi, Le cupole del Brunelleschi, Bologna: Edizioni Calderini, 1982; C. Blasi, F. Ottoni, E. Coïsson, C. Tedeschi, 'Battistero di San Giovanni in Firenze. Note su dissesti, lesioni e catene', pp. 119-133, in F. Gurrieri (Ed.), Il Battistero di San Giovanni. Conoscenza, diagnostica, conservazione, Florence: Mandragora, 2017.
[8] C. Guasti, La Cupola di Santa Maria del Fiore illustrata con i documenti dell'Archivio dell'Opera secolare, Florence: Barbèra, Bianchi e Comp, 1857, pp. 177-183.
[9] F. Ottoni, C. Blasi, 'Hooping as an ancient remedy for conservation of large masonry domes', International Journal of Architectural Heritage, Vol. 10, no. 2-3, 2016, pp. 164-181.
[10] Biblioteca Nazionale Centrale di Firenze (BNCF), Ms.II.21, c. 31r.
[11] Ibid.
[12] B. S. Sgrilli, Descrizione e studi dell'insigne fabbrica di S. Maria del Fiore, Florence: Per Bernardo Paperini, 1733, tav. VII.
[13] G. Rondelet, Trattato teorico e pratico dell'arte di edificare, Mantua: a spese della società editrice coi tipi di L. Caranenti, 1831, tav. CLXXXIX.
[14] Durm, Die domkuppel in Florenz und die kuppel der Peterskirche in Rom, (Note 2).
[15] Prager, G. Scaglia, Brunelleschi. Studies of His Technology and Inventions, (Note 7).
[16] M. Ricci, 'La catena de' castagni della cupola di S. Maria del Fiore', pp. 89-93, in G. Tampone (Ed.), Legno e restauro. Ricerche e restauri su architetture e manufatti lignei, Florence: Messaggerie Toscane, 1989.
[17] Sgrilli, Descrizione e studi dell'insigne fabbrica di S. Maria del Fiore, (Note 12).
[18] Ricci, 'La catena de' castagni della cupola di S. Maria del Fiore', (Note 16); H. Saalman, Filippo Brunelleschi. The Cupola of Santa Maria del Fiore, London: A. Zwemmer Ltd, 1980; S. Di Pasquale, Brunelleschi. La costruzione della cupola di Santa Maria del Fiore, Venice: Marsilio Editore, 2002.
[19] Studio Scaletti and Studio Comes, May 2018.
[20] M. Haines (Ed.), The Years of the Cupola. Digital archive of the sources of the Opera di Santa Maria del Fiore, 1417-1436, Florence: Opera di Santa Maria del Fiore, 2015. http://duomo.mpiwg-berlin.mpg.de (consulted on 15^{th} May 2021).
[21] Conversions were made according to the 'Tavole di riduzione delle misure e pesi toscani alle misure e pesi analoghi del nuovo sistema metrico dell'impero francese', Florence: Presso Molini, Landi e comp., 1809.
[22] Studio Scaletti and Studio Comes, (Note 19).
[23] AOSMF, II.4.9, n° 71v.
[24] P.P. Derinaldis, G. Tampone, 'The failure of the timber structures caused by incorrect design-execution of the joints. Two case study', in Proceedings of ICOMOS IWC – XVI International Symposium, Florence, Venice and Vicenza 2006.
[25] AOSMF, V.3.18 (II), f. 33; AOSMF, V.3.19, f. 166; AOSMF, V.3.42, f. 268.
[26] AOSMF, XI.3.3, fasc. 93 (Woodworker); AOSMF, XI.3.3, fasc. 84 (Blacksmith); AOSMF, XI.2.5, fasc. 23 (Baccani).
[27] AOSMF, XI.2.14, fasc. 1; AOSMF, XI.3.17, n°61; AOSMF, XI.3.20, n°90, 117; AOSMF, XI.2.16, fasc. 16.
[28] AOSMF, XI.3.20, f. 90.
[29] G. Veneroni, Dittionario italiano e francese, Venice: Appresso Lorenzo Basegio, 1703.
[34] G. Valadier, L'architettura pratica, Rome: Con permesso dei superiori, 1831, Tav. LXVIII.
[31] N. Cavalieri San Bertolo, Istituzioni di architettura statica e idraulica, Florence: A spese dell'ingegnere Vittorio Bellini, 1832.