Medieval formwork imprints in the Basilica of St Anthony in Padua

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Introduction

The construction of the Basilica of St Anthony started outside the walls of Padua shortly after the death of the Portuguese-born Franciscan friar in 1231 (Fig. 1). Already largely completed around 1310, the brick church and its timber domes were remodelled in the following centuries with the reconstruction of the bell towers and choir dome (fifteenth century), the addition of an eastern chapel or the replacement of five timber domes after a fire (eighteenth century). In the absence of medieval building archives and despite decades of art historical research, the understanding of the construction sequences remained subject to conflicting theories until recently [1].

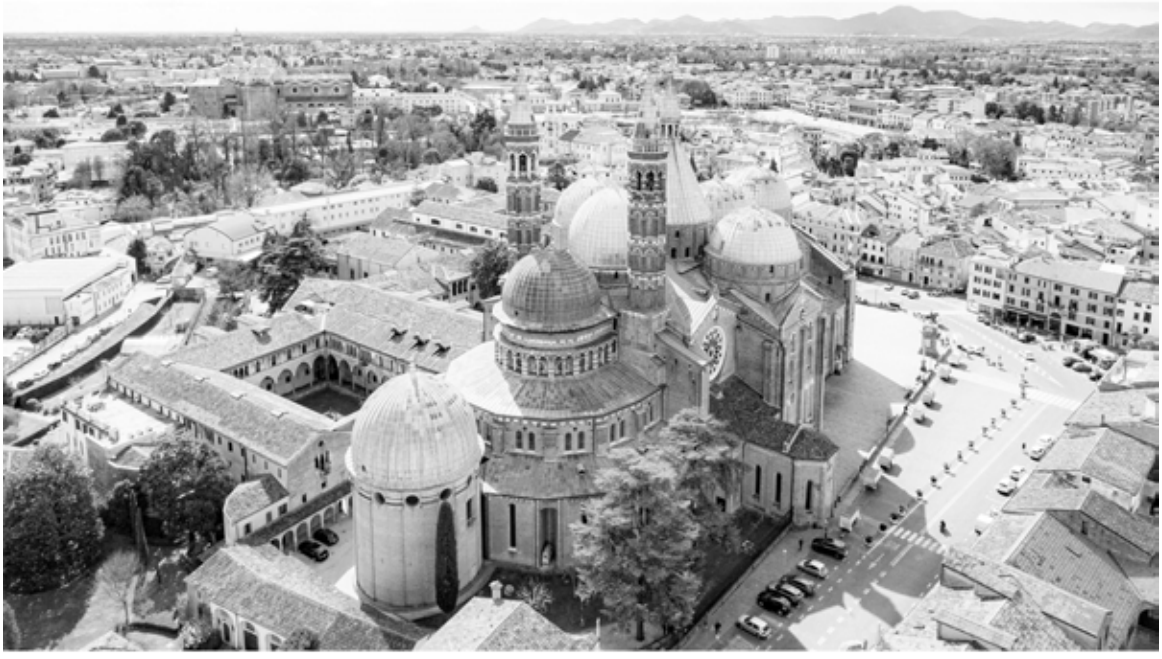

Figure 1: North-eastern view of the Basilica of St Anthony in Padua (picture: Davide Boggian and Giacomo Ravenna)

Since 2019, the Basilica has been investigated from a building archaeology and construction history perspective by researchers of the Institute of Construction History and Preservation (ETH Zurich), under the direction of Prof. Stefan M. Holzer and in collaboration with the *Delegazione Pontificia per la Basilica di Sant'Antonio in Padova*. After a thorough analysis of the original brickwork supported by digital surveys and the absolute dating of its timber domes using dendrochronology, a scientifically-sound image of the early history of the pilgrimage landmark has started to emerge [2].

The present paper on formwork imprints sheds light on subtle details recorded in the intricate network of passages and rooms hidden in the brick walls of the massive church. From the survey of traces of temporary timber structures – enriched by the discovery of intact elements – the construction techniques of short-span barrel vaults and medium-span pointed arches can be described with high precision. The missing portions of temporary works dismantled without leaving traces are hypothetically reconstructed based on well-documented examples gathered in a recent monograph [3]. Furthermore, the findings are supported by preliminary results from absolute dating (dendrochronology and radiocarbon) and wood species analyses. Finally, the paper introduces ongoing investigation using similar methods to reveal the erection process of the eight large-span masonry domes.

Short-span barrel vaults

The masonry of the western half of the church, likely built between the 1230s and 1260s, is partly hollowed out by more than 300 metres of narrow corridors leading to each roof and attic. This network, the length of which has to our knowledge no equivalent in medieval religious architecture, was certainly designed to facilitate construction, ease maintenance and provide a fast access to each part of the edifice in the event of a fire. Unlike exposed structures, most of these galleries underwent no modifications whatsoever since the thirteenth century, making it a privileged access to the Basilica's original state.

The width of these corridors varies between 55 and 80 cm and their inclination can reach up to 50°. The highest corridors are to be found in the front facade (3.65 m), likely explaining why some components of the original formwork which do not hinder the passage were left in place (Fig. 2). These transversal elements consist of 3.5-cm thick boards inserted after completion of the vertical bricklaying and before the start of the barrel vault (Fig. 3). As revealed by imprints in the abundant mortar binding the bricks, each board was topped by a semi-circular element (likely made of two or three pieces) supporting about ten longitudinal boards, the positions of which are still perfectly discernible on the mortar or at the ends of the corridors where corresponding notches can be observed. Some of these longitudinal elements, albeit absent in the front façade, have been recovered intact in other corridors above the crossing and at the base of the northern bell tower.

Figure 2: Boards used for vaulting the corridors of the front façade in the thirteenth century (picture: author)

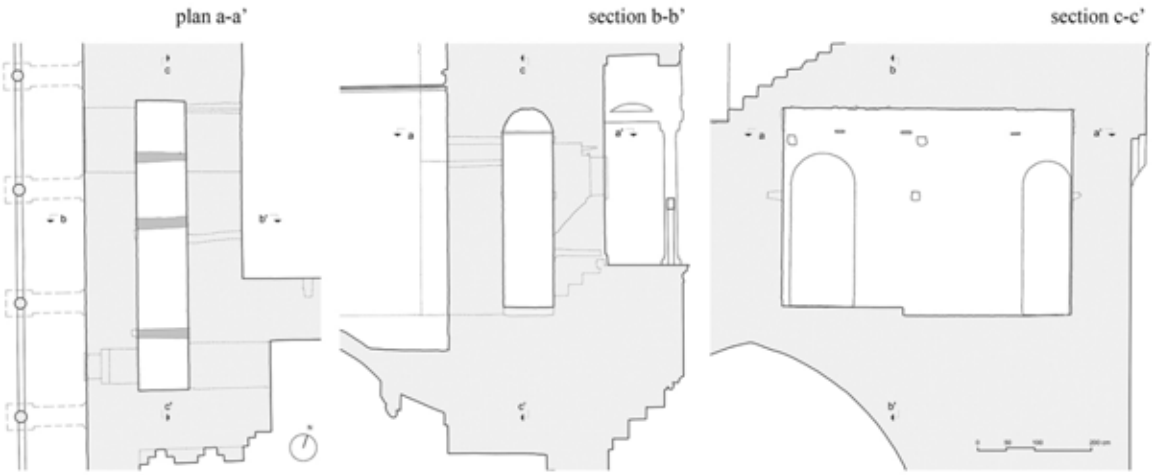

Figure 3: Three out of four original boards survived in this north-western corridor of the façade (drawing: author)

Wood species analyses have indicated that the transversal boards consist of spruce, unlike the original roof structures for which fine-grained larch were felled in the last quarter of the thirteenth century [4]. Some boards are also drilled multiple times, indicating that they could have been part of a previous structure, likely a scaffolding fastened with ropes. Thus, as one might have expected, medieval builders did not use timbers of similar qualities for temporary formwork and permanent roof structures.

The relatively large sections of preserved timber have raised hopes of dating the surrounding masonry using dendrochronology, but such attempts have not yet been successful due to the lack of reference curves for thirteenth-century spruce in the region. Samples of these boards were thus extracted for further radiocarbon analyses at the Laboratory for Ion Beam Physics (ETH Zurich).

Although rare, similar imprints of boards on intradoses of barrel vaults (showing a striking resemblance to modern concrete structures) enable the tracing of such formwork back to second-century Italy [5]. As a first step in the wide range of vaulting techniques applied in the Basilica of St Anthony, the exceptional preservation of some original boards offers a more precise understanding of an ancestral vaulting technique as well as a unique opportunity to date varied parts of the building.

Medium-span arches

The second example of formwork imprints relates to traces recorded in two hidden rooms formed by pointed arches at the base of each bell tower, connecting the spiral staircases of the buttresses to the attics of the ambulatory (Fig. 4). The sole presence of such arched rooms led previous scholars to surmise that these are the remains of an open upper gallery in a former variant of the ambulatory [6]. Yet it seems more likely that the primary role of these rooms was to lighten the masonry and help spread vertical loads to two distinct supports. Moreover, their surfaces were never intended to be visible, or they would still bear traces of plaster.

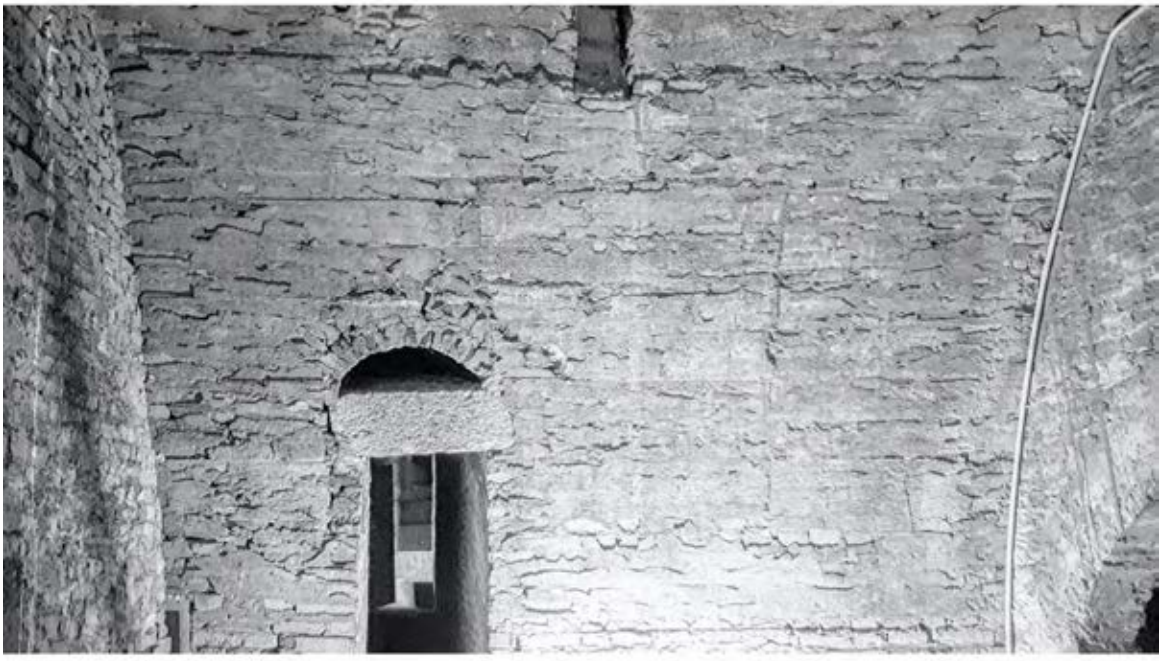

Figure 4: Traces of wooden boards on the intrados of a pointed arch under the northern tower (picture: author)

Based on a photogrammetric survey and detailed onsite observations, the traces of formwork on the intrados of the northern arch have been precisely mapped. Similar imprints can be observed on the twin room under the southern tower, but the presence of the clock mechanism complicates their recording. Aligned with the edge of the arches, two non-structural brick walls were raised subsequently to close the rooms towards the transept and the roof of the ambulatory. Regarding the construction of the 5.5-m long arches, three main steps can be identified from the changing textures of the mortar (Fig. 5).

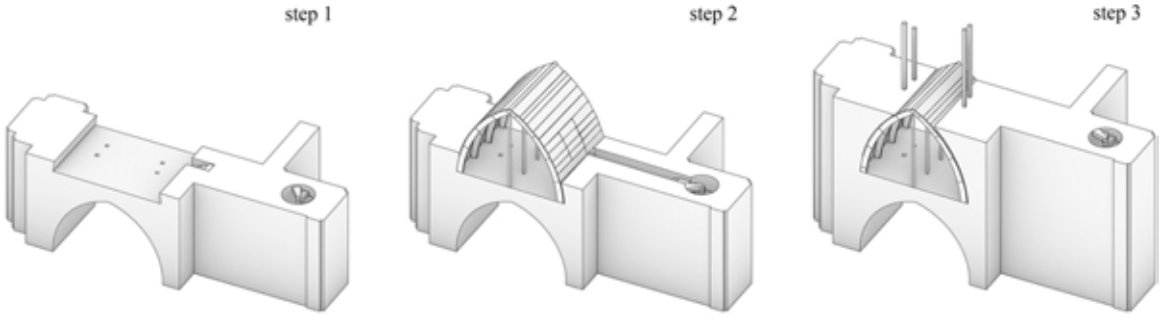

Figure 5: Construction sequence of the pointed arch under the northern tower (model: author)

Firstly, the landing of the arch was erected with the surrounding walls without any formwork until a height of 85 cm. In this lower section of the arch, the mortar joints are flush with the surface and were thus systematically smoothed by the masons who could freely access the intrados under construction (step1).

Then, a temporary timber structure was installed between the pre-existing layers of bricks acting as abutments (step 2). The main supporting elements consisted of four curved arches, each composed of two layers of 4-cm thick boards. The precise position and composition of these laminated arches can be obtained from their imprints left on the second type of mortar finishing. Indeed, between a height of 85 and 125 cm, the four timber arches were directly in contact with the masonry during the laying of the bricks. As masons could not reach the intrados anymore, the mortar joints are extruded in this cruder section of the arch.

Finally, above 125 cm and until the top of the room, the bricks were placed against a series of boards nailed to the underlying timber arches (step 3). The width of these boards varied between 14 and 50 cm and their length between 120 (in the lower part) and 410 cm (in the upper part). In cross section, the arch is 55 cm thick and randomly composed of two stretchers or one stretchers and two headers. Before reaching the top of the formwork, builders wisely inserted four timber posts among the bricks to prepare as many holes for the ropes operating the bells. Beyond a careful execution of this arch, the holes indicate that the position of the original towers did not largely differ from their fifteenth-century reconstruction.

Once the mortar had perfectly cured, the temporary structure was removed from beneath, not without leaving on the surface a few wood splinters ripped from the longitudinal boards. At this stage of the investigation, a fragment of wood extracted from the intrados has been imprecisely dated with radiocarbon to the twelfth century, decades before the start of the construction. This first result confirms that temporary structures were often composed of (very) old timbers. It also stresses that one should be critical when dating historical structures based on such fragments, or at least that such analyses should not be based on just a few samples. In the present case, a new set of samples collected over the entire height of the bell towers is currently under investigation to clarify their construction sequences.

Large-span domes

A last example of traces left by temporary structures can be observed on the intradoses of the masonry domes of the Basilica, the diameter of which varies from 14.3 to 14.46 m and the thickness from 32 to 43 cm. Although direct formwork imprints are masked by plaster and paint (Fig. 6), geometrical deformations introduced by the centring clearly appear on the laser scan survey, as the horizontal deviations from ideal circles can reach up to 8 cm. (Fig. 7). The first traces start about 120 cm above the windows, indicating that the lower halves of the drums were likely raised without formwork. In the upper parts, the traces show the arrangement of 16 equally spaced centres converging at the highest point of the slightly ogival dome. How the centring was assembled and supported is currently under investigation. By systematically comparing the position of the centres to those of the putlog holes visible on the exterior of the drums (using drone photogrammetry) or under the plaster of the intrados (thermal imagery), one should be able to determine whether the hemispherical formwork was “flying” or supported by a 30-m high scaffolding (examples of both systems can be found in [7]).

Compared to Gothic vaults which have been the subject of many studies supported by detailed onsite investigations, there is so far little research on the erection process of brick domes in Europe. Hence, the ongoing research on the domes of St Anthony will help fill this gap in medieval construction history, thanks mostly to the precise documentation of traces left by scaffolds, centring and formwork.

Figure 6: Wide-angle view of the intrados of the façade dome (picture: author)

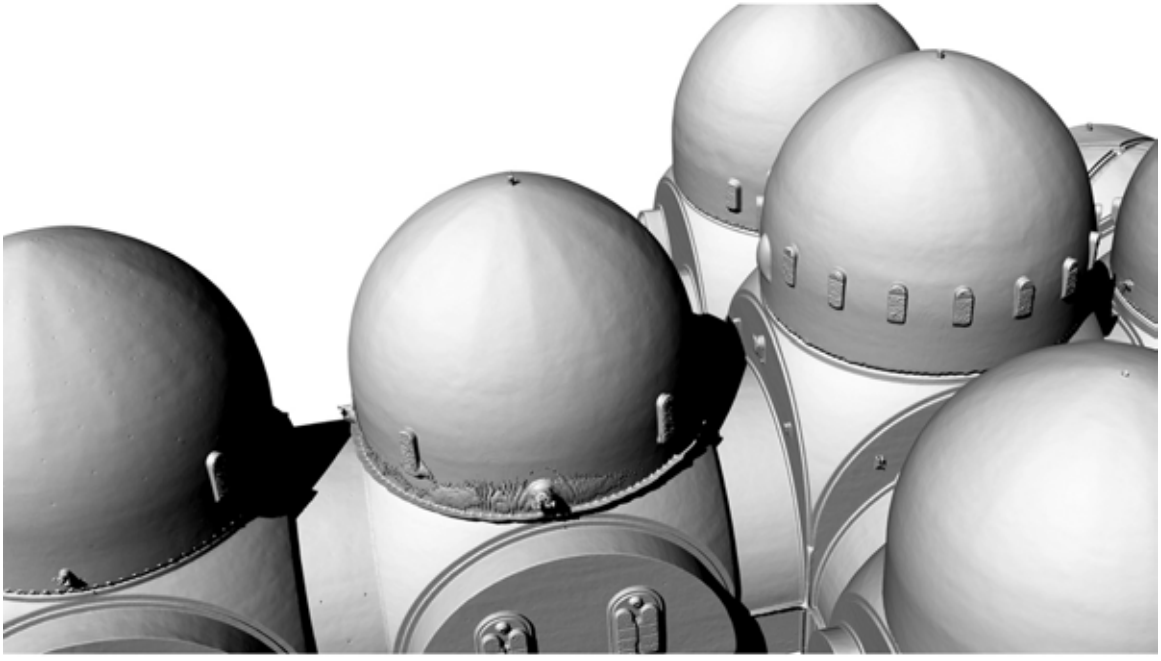

Figure 7: The meshed model of the intrados of the domes reveals traces of centring (model: author)

Conclusions

In the scope of an ongoing research project on the Basilica of St Anthony in Padua, the building techniques of short-span corridors, medium-span arches and large-span domes have been investigated based on detailed onsite surveys. The erection process of the first two examples has been depicted with high accuracy thanks to their formwork imprints and some intact elements, paving the way for a similar analysis of the domes.

The investigations on temporary works reveal that the large volumes of timber used during the construction of a basilica left not only imprints, but also fragments of wood embedded in the mortar. The knowledge of building techniques can thus significantly accelerate the discovery of such samples as one can concentrate research efforts on surfaces where the two materials were in contact. Applied in the present project, this method has already proven effective to recover more than 20 intact fragments of wood, also in parts of the building where all carpentry burnt in the eighteenth century. This fruitful combination of construction history and building archaeology enables a finer understanding of medieval building techniques in Northern Italy and in fine the absolute dating of the transformations of the Basilica of St Anthony.

Acknowledgements

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