Architectural History 66 (2023), 21–56. © The Society of Architectural Historians of Great Britain 2023
doi:10.1017/arh.2023.3

SHORTER NOTICE

Antonio da Sangallo the Younger and St Peter's Keys: Building Technology and Vitruvian Theory

by SAMUEL HOLZMAN AND CAROLYN YERKES

ABSTRACT

This article reconstructs an exceptional lifting device — a cruciform lewis — drawn by Antonio da Sangallo the Younger (1484–1546) at St Peter's Basilica in Rome and connects it to the other drawings, mainly of Vitruvian theory, on the same sheet (now in the Uffizi in Florence). Elements of this sheet, dated to January 1542, have been studied in isolation, but this article connects them, underscoring how Sangallo's theoretical interests in the art of building and the practicalities of masonry construction were inseparable. A question posed by the sheet is whether it documents Sangallo's archaeological discoveries of ancient Roman tools or presents newly contrived ones — categories that Sangallo's drawings move fluidly between. His studies should be understood in relation to the immediate problems that he faced on the building site of St Peter's and within the broader context of other Renaissance drawings of machines, such as those by Francesco di Giorgio and Leonardo da Vinci.

Embedded in Giorgio Vasari's 'Life of Brunelleschi' (first published in 1550), that origin story of Renaissance architecture, we find an account of a particular constructional instrument. Writing of the transformative trip to Rome that Filippo Brunelleschi supposedly made from Florence in 1401 or soon afterwards, Vasari made a pair of observations about the architect's antiquarian studies:

> he noted the ways of making buildings secure by binding the stones together, by iron bars, and by dove-tailing; and, discovering a hole hollowed out under the middle of each great stone, he found that this was meant to hold the iron instrument, which is called by us the *ulivella*, wherewith the stones are drawn up; and this he reintroduced and brought into use afterwards. He then distinguished the different orders one from another — Doric, Ionic, and Corinthian; and so zealous was his study that his intellect became very well able to see Rome, in imagination, as she was when not in ruins.[1]

The 'instrument', the *ulivella* (literally 'olive tree') or sometimes *livella*, is commonly known as the lewis or, from its shape, St Peter's keys. At its simplest, it is an inverted wedge consisting of one inner and two outer parts inserted into a cavity in a stone block; the cavity is cut so that it is larger at the bottom than at the top, and the snug friction fit created when the inner part of the wedge is inserted between the outer parts allows the stone to be hoisted. Lewises used in the construction of Florence cathedral (the dome of which was built to Brunelleschi's design between 1420 and 1436) are in the collections of the Duomo museum (Fig. 1). In one short passage, Vasari excavated the lewis from antiquity and associated it with the categorisation of the architectural orders.

Vasari's passage is partly myth-making, not an immediate historical account — he was, after all, writing 150 years after the fact. Antonio Manetti's biography of Brunelleschi from seventy years earlier, on which Vasari based most of his own life of the architect, made no reference to the *ulivella*.[2] What was significant for Vasari was the resuscitation of the lewis from ancient Rome, crediting Brunelleschi with bringing it back into use through his archaeological investigations, and his parallel research in classifying the ancient architectural orders.[3] What we get from Vasari, then, is not necessarily a story of what Brunelleschi actually did, but of how those two things — the revival of a particular instrument for lifting stones and the differentiation of the columnar orders deduced from ancient remains — were perceived in mid-sixteenth-century Florence as analogous architectural endeavours.

These two matters were also paired in the decade before the first edition of Vasari's *Lives* (1550) on a sheet of drawings, Uffizi 826A, made by Antonio da Sangallo the Younger (1484–1546), the most prolific architect working in Florence and Rome at that time (Figs 2 and 3). Sangallo is the first architect known to have archived his own drawings, and this example shows how paper had become the medium of exploration, and the means for recording and developing ideas. Across both sides of the single sheet, lewises and columnar orders appear side by side and are sometimes intermingled. This article reconstructs in detail the remarkable type of lewis drawn by Sangallo and connects it with a nearby drawing showing the cutting of a Corinthian pilaster capital at St Peter's Basilica, as well as with other drawings, mainly relating to Vitruvian theory, on the same sheet. While individual drawings on the sheet have been studied in isolation, this article not only connects them all together, but also adopts a more holistic approach to Sangallo's use of drawing as a conceptual and professional tool. First we discuss all the drawings on the sheet in sequence, arriving finally at the drawings of the lewis, which we examine in detail and relate both to the history of the tool and the construction of St Peter's. We then explore why the lewis drawing is accompanied by depictions of the orders. What emerges is a sense of Sangallo's interpretation of Vitruvian theory and its practical applications, an interpretation that roots the art of building firmly in the particulars of masonry construction.

SANGALLO'S DRAWINGS ON UFFIZI 826A

Sangallo's vast archive of architectural drawings reveals the inner workings of a large professional office, one in which the lead architect made drawings to develop designs and direct work on building sites, as well as to engage in more theoretical pursuits. The proximity of the drawings of the lewis and the orders on one sheet of paper suggests the latter and also connects with the former. The sheet was once folded down the middle to form two leaves and so, rather than consider it in terms of its recto and verso sides as is customary, it makes more sense to think of it as a sequence of four pages: A, B,

https://doi.org/10.1017/arh.2023.3 Published online by Cambridge University Press

Fig. 1. *Lewis irons in the collections of the Museo dell'Opera del Duomo, Florence*

C and D (Fig. 4).[4] Sangallo's lewis, drawn on the last page (D), is our main subject, but we approach it by first discussing the contents of the three preceding pages. The drawings are explained in copious annotations (fully transcribed in the appendix on pages 46–53), and the drawings and notes together contextualise Sangallo's interest in the lewis and place his study of building technology within the broader framework of his architectural theory.[5]

The first page (A – Fig. 3, right) shows the orders and its drawings are well known to architectural historians. They have been interpreted as indicative of Sangallo's attitude towards historical precedent. Sangallo scribbled a dated note on the page — a receipt for wine purchased on 25 January 1542 — that helps associate the drawings with architectural projects ongoing at that time, among them his continuing work on St Peter's. Their renown, however, derives from the short but suggestive comment that Sangallo wrote about the orders and their origins, and from the use of the drawings on this page to reconcile and explain certain features of capital design. In a pair of studies at the top left, he superimposed components from the Doric, Ionic and Corinthian orders into a single capital and, in between the two drawings, wrote: 'These capitals are born the one from the other, as you can see here.' As Paola Zampa has explained, in the first extensive analysis of these drawings, Sangallo sought to find a single archetype relatable to all three orders.[6] This drive to identify a unifying paradigm, rooted in Vitruvian rules, for the plurality of ancient examples was subsequently described by Manfredo Tafuri as a 'drastic reduction'.[7] He compared Sangallo's graphic process in these studies to a metamorphosis, an abstraction of forms that censures variety and is, at its core, anti-historicist because it divorces architectural forms from the specific circumstances that shaped them.

Certain aspects of Tafuri's argument hold true when we continue on from these two drawings and consider the others adjacent to them on the same page. In the top-right corner, Sangallo sketched two different figurated Corinthian capitals that he was

https://doi.org/10.1017/arh.2023.3 Published online by Cambridge University Press

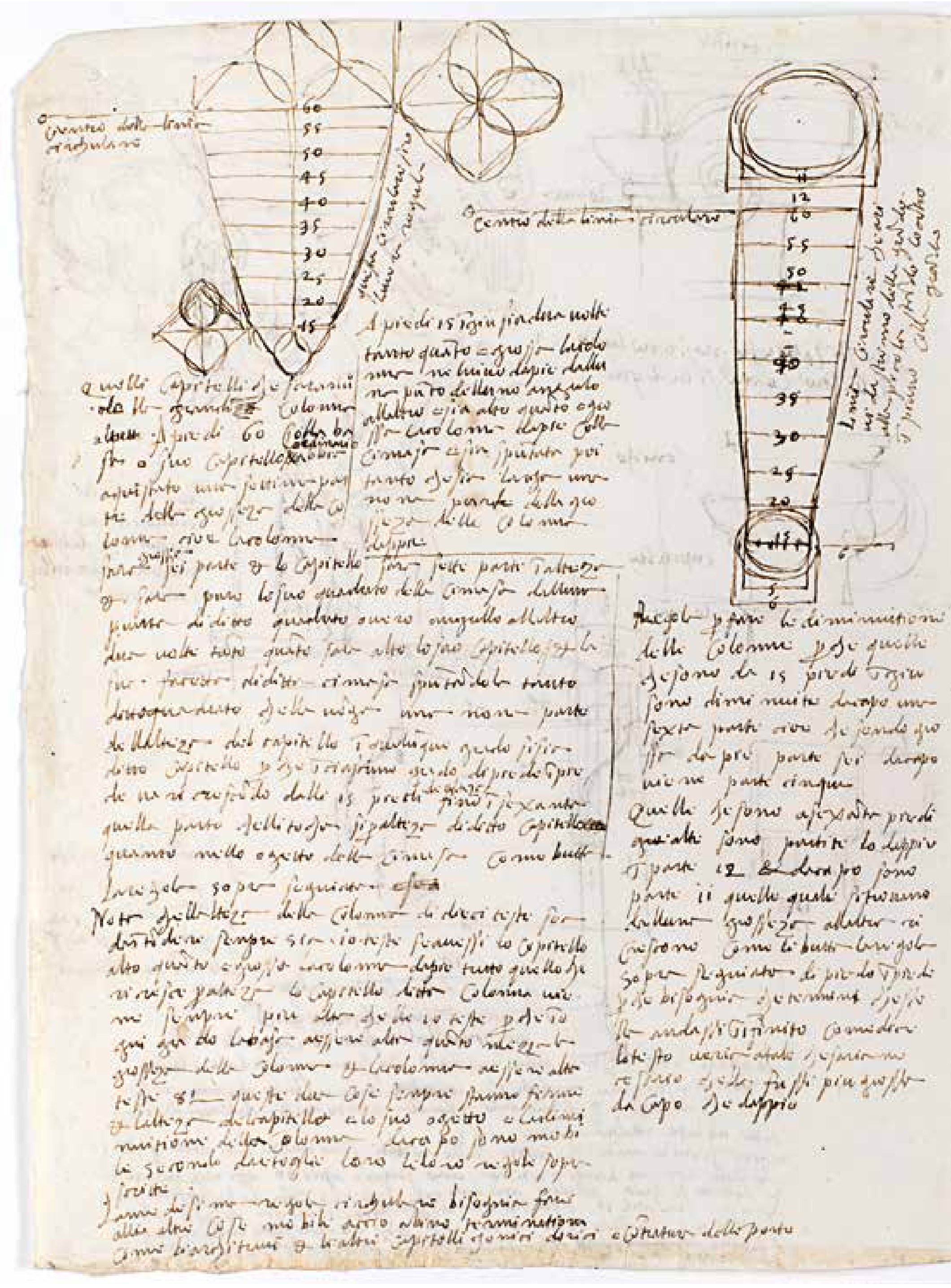
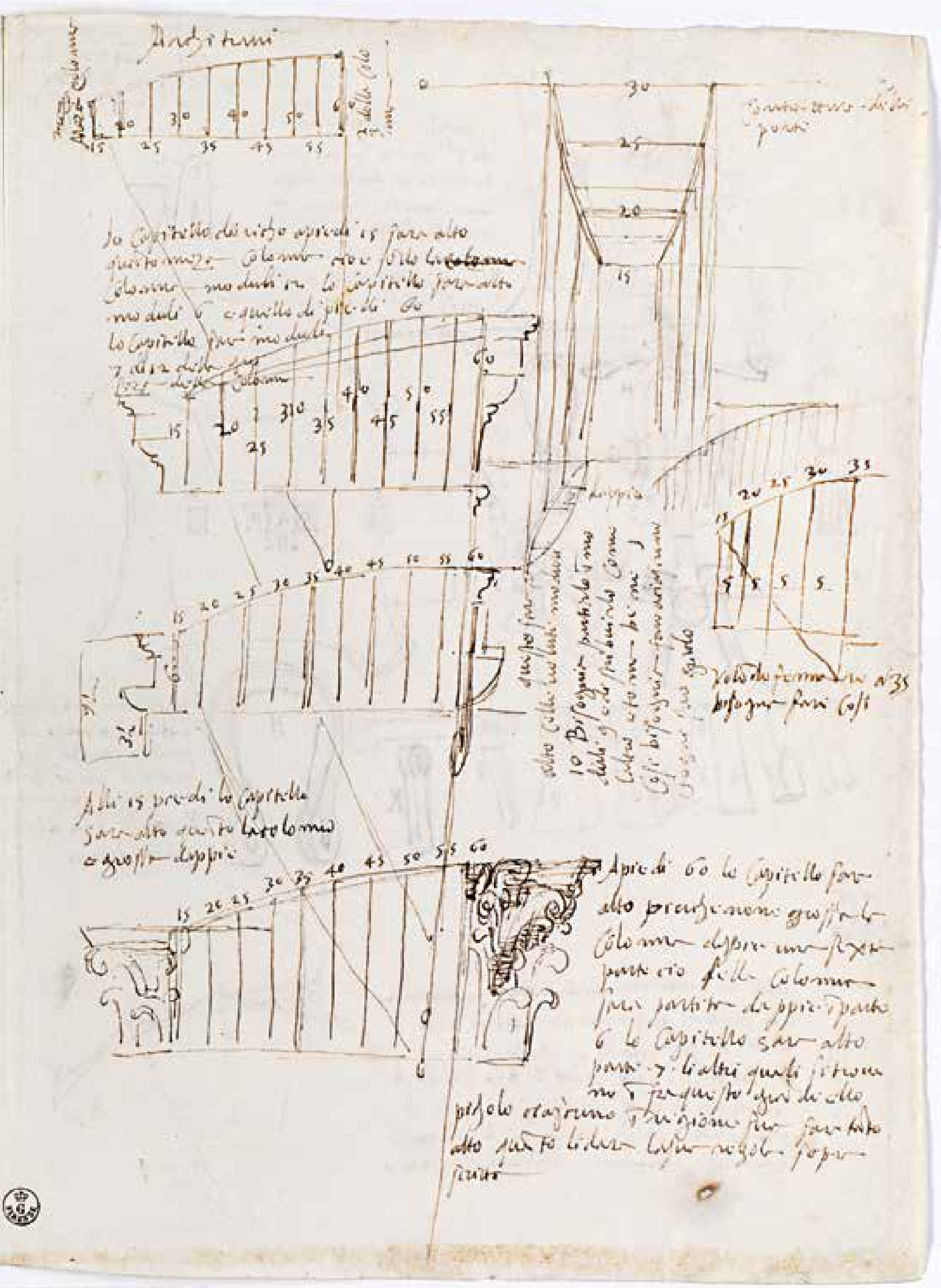


Fig. 2. *Antonio da Sangallo the Younger, studies of columns and capitals, 1542, ink on paper, 215 × 290 mm (Florence, Uffizi 826A recto)*

https://doi.org/10.1017/arh.2023.3 Published online by Cambridge University Press



https://doi.org/10.1017/arh.2023.3 Published online by Cambridge University Press

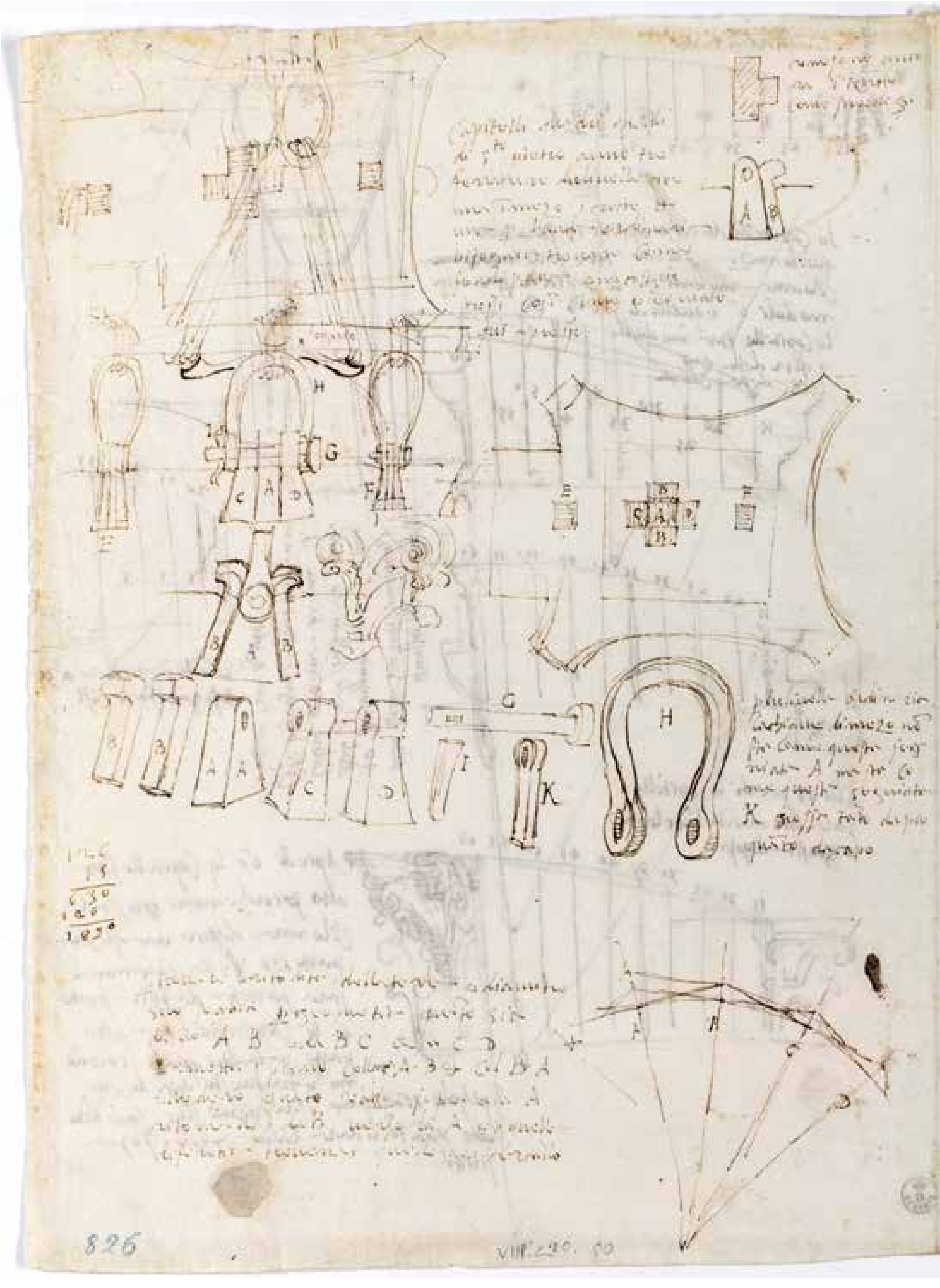
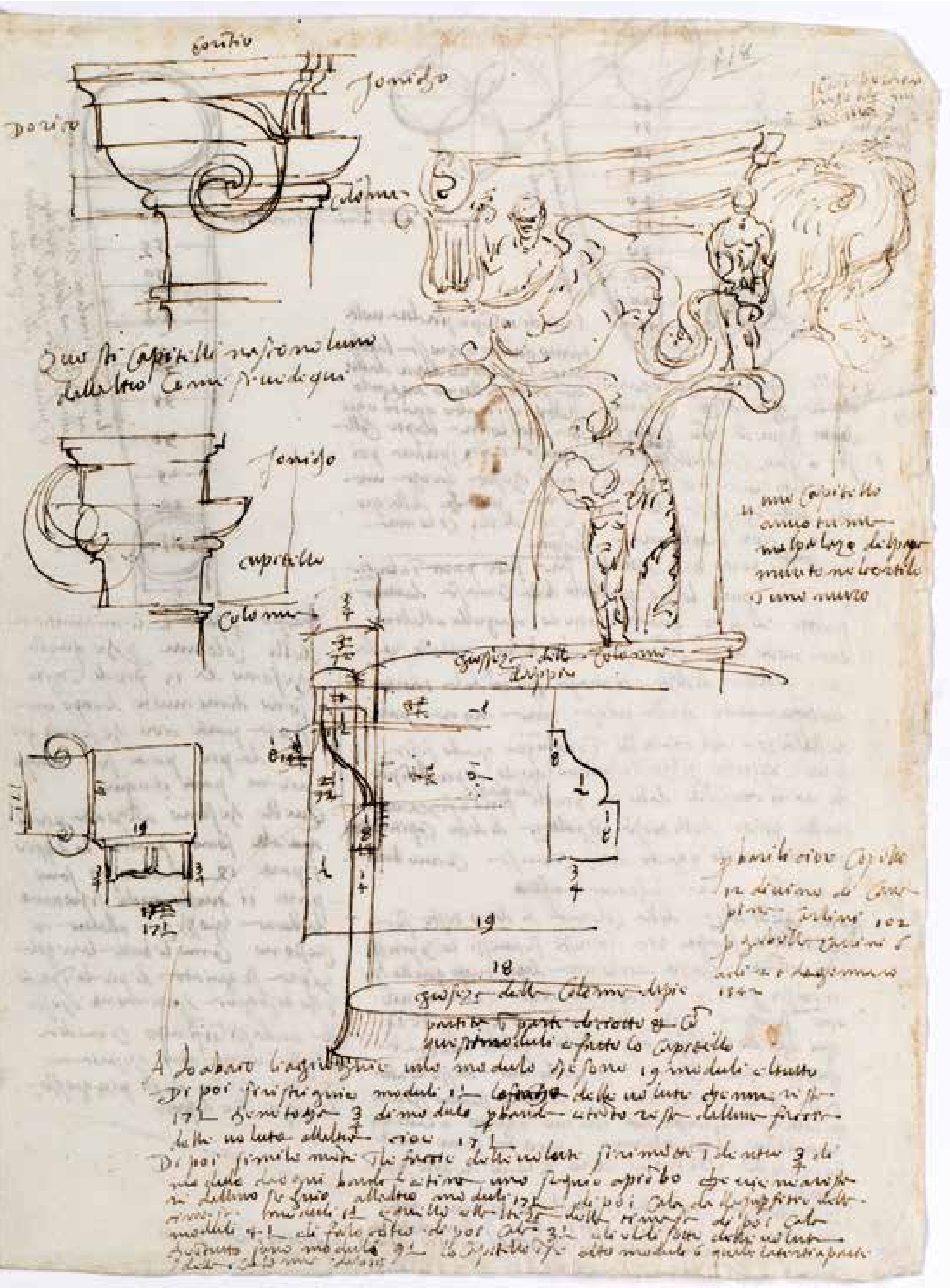


Fig. 3. *Antonio da Sangallo the Younger, studies of a lifting device, two ancient capitals, the proportions of the orders and a method for calculating the circumference of the earth, 1542, ink on paper, 215 × 290 mm (Florence, Uffizi 826A verso)*



https://doi.org/10.1017/arh.2023.3 Published online by Cambridge University Press

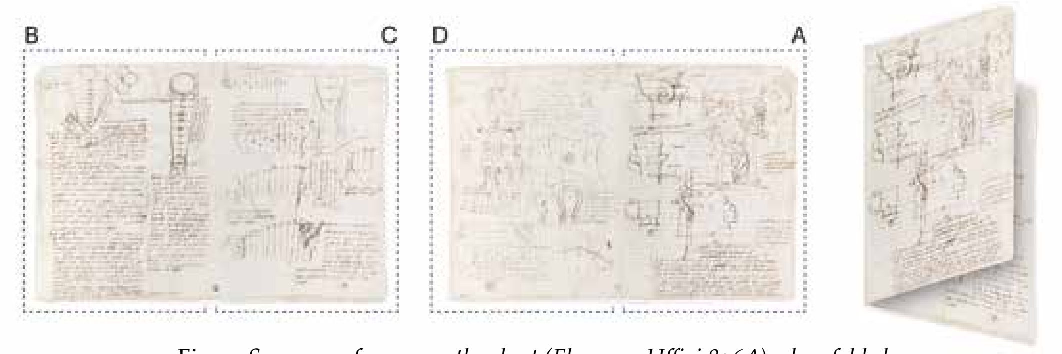


Fig. 4. *Sequence of pages on the sheet (Florence, Uffizi 826A) when folded*

nevertheless able to link together through a specific formal similarity. Although the capitals remain unidentified, it is clear from their annotations that Sangallo saw them at two separate sites. The larger drawing has a winged triton at the capital's upper centre holding a lyre, with one figure tucked inside the capital's lower leaf and another standing under the abacus atop an upper leaf. A note explains that the capital had been found the previous year in the pope's palace, inside a wall during the construction of the 'cortile', but it is not clear whether it was found in the Farnese Palace — the residence of Pope Paul III, which was under construction in the 1540s — or at the Vatican. Next to this drawing, Sangallo sketched a detail of an eagle from a capital located at the house of the Porcari family, near Santa Maria sopra Minerva.[8] Given that he was working on the wall tombs (designed *c.* 1535) of Leo X and Clement VII for this church at the time, he would have come regularly to the neighbourhood. These two capital drawings, like the others amalgamating the different orders, offered creative alternatives for how to fill the zone between the uppermost leaf of the Corinthian capital and its abacus.[9]

Below his studies of Corinthian capitals, Sangallo further addressed the Ionic. In the three drawings at the page's centre, he developed a close reading of the description of the Ionic capital in Vitruvius's third book into a working rule for the capital's design, as Francesco Benelli has demonstrated.[10] The long annotation details how to proportion the capital's volutes using the column diameter as the module and dividing it into eighteen parts. In setting his Vitruvian prescription for the Ionic immediately alongside his chosen examples of the Corinthian, Sangallo juxtaposed two distinct types of evidence for how to codify a columnar order: text and drawing. Returning to the top-left corner of the sheet, Sangallo's superimposition of all three orders can now be re-read as a study of how the Doric fits into a notional overall system.

Sangallo's equation of Doric and Ionic in these top-left drawings depends on the analogy of the abacus of the Doric capital and the volute zone of the Ionic, both filling the middle space between the echinus and the capital's crowning moulding.[11] The Corinthian is implied by the possible extension of the capital's neck. The sculpturally more elaborate Corinthian alternatives on the right continue this idea, with the zone between the drum of acanthus leaves and the abacus being populated by sculpted figures (of a triton and eagle) that are in effect interchangeable. Although we have

https://doi.org/10.1017/arh.2023.3 Published online by Cambridge University Press

discussed these drawings in terms of their individual locations on the page, they collectively form what is in effect a cycle with no set starting point. Sangallo's attitude, as previously mentioned, was anti-historicist in the sense that he had no particular concern for the variety of capitals and their origins. Yet the proportional rules for the capitals are still substantiated by specific examples because Sangallo shows how even these illustrated fragments, however eccentric, still adhere to the same more general proportional system.

For Sangallo, the validity of his system sprang from its flexible accommodation of unusual but authentic products of antiquity. Over the next two pages (B and C), he continued his streamlining of Vitruvius's at times convoluted instructions for architects. As Zampa and Pier Nicola Pagliara have explained, Sangallo presented a graphic method for generating proportional adjustments to column shafts, capitals (Doric, Ionic, Corinthian) and entablatures for columns from 15 to 60 *piedi*.[12] The illustrations and text respond directly to passages of Vitruvius that provide guidelines for optical refinements to columnar orders according to scale.[13] Where Vitruvius offered fixed formulas for columns falling within 5 ft height ranges (15–20 ft, 20–25 ft, and so on), Sangallo devised a scheme for continuous adjustment reckoned by means of a circle segment's intersection with a scale graduated with column heights, a method he termed a *regola circhulare*. The long texts and accompanying illustrations of such a geometric calculating system are indications of his concerns with designing buildings of different scales. In the background of these abstract, aesthetic formulations are the inherent construction challenges that accompany building at giant scale, which Sangallo turns the page to address.

On the sheet's fourth page (D), Sangallo drew the lewis, but showed it above a diagram for calculating the circumference of the earth.[14] Measuring the earth's circumference had been presented by Pliny the Elder as one of the great intellectual challenges of antiquity, Pliny observing that it was most accurately estimated by Eratosthenes of Cyrene but attempted by others with ingenuity and occasionally trickery.[15] This intertwining of antiquarianism and geodesy — the empirical measurement of the earth's size and shape — reached its apex in the eighteenth century, when archaeological missions to Greece sought to discover ancient foot measurements so that Eratosthenes's calculation could be compared with results obtained from the latest polar and equatorial expeditions.[16] Sangallo, for his part, was musing fancifully about large-scale surveying and was seemingly trying his hand at a Greco-Roman enigma that had acquired a new relevance in the age of exploration.

SANGALLO'S LEWIS

If Sangallo's studies of Vitruvius and ancient fragments show the professional architect seeking practical applications from the evidence of antiquity, his circumference diagram demonstrates the degree to which he occasionally pursued erudition for its own sake. Sangallo instrumentalised his knowledge, but he revelled in it too. In these enquiries, he also used drawing to think abstractly through essentially physical problems. His study of the lewis continues the same theme. Here, he confronted the challenge of lifting heavy stones through a drawn analysis of a hoisting device.

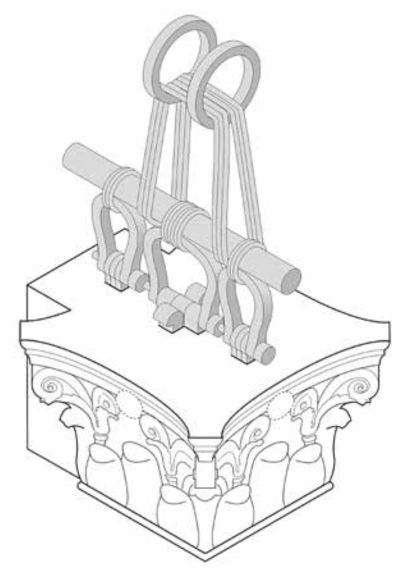


Fig. 5. *Diagrammatic view by the authors of the lifting device drawn by Antonio da Sangallo*

Sangallo presented his version of the lewis on page D (see Fig. 3, left) in an annotated sequence of plans and sections together with an exploded perspective that disassembles the instrument into its component parts. The sequence begins at the top left of the page with a rather faint plan of a stone block that includes both a capital for a pilaster and a portion of an adjacent wall. An annotation explains that this block belongs to a large square capital at St Peter's. Sangallo is careful to show that the three lewises used to hoist the block are positioned not over the centre of the pilaster capital but over the centre of gravity of the block as a whole: one for the cross-shaped socket in the middle, and one for each of the rectangular sockets on either side. Further section sketches show how each lewis is assembled from multiple wedge-shaped keys, which must be inserted in sequence to create a tight fit, and attached to horseshoes (*ferrature*) for lifting them.

It is possible to reconstruct the lifting rig that Sangallo drew in several, partly overlapping, drawings (Fig. 5). His device has the three lewises yoked to a bar (the term *legnio* probably indicating a wooden beam), which is in turn attached via straps or ropes to two rings above it. These rings would connect the device to a hoist. In Sangallo's sketch section of the pilaster capital and lewis keys (see Fig. 3, left, on the page's left below the plan), a horizontal line indicates the top surface of the stone block. Lettering on each of the three lewises locates them in the adjacent plan to the right, and the central lewis is also shown in detailed diagrams above and below. The lewises on either side of the central one, marked *E* and *F*, are simpler in design with just three keys — two inverted wedges and a straight-sided shim between them. This three-key lewis was the most common type (as seen in Figure 1), and perhaps because it was so familiar to Sangallo he made no other drawings of it. The added complexity of the central lewis and its cross-shaped socket required further explanation.

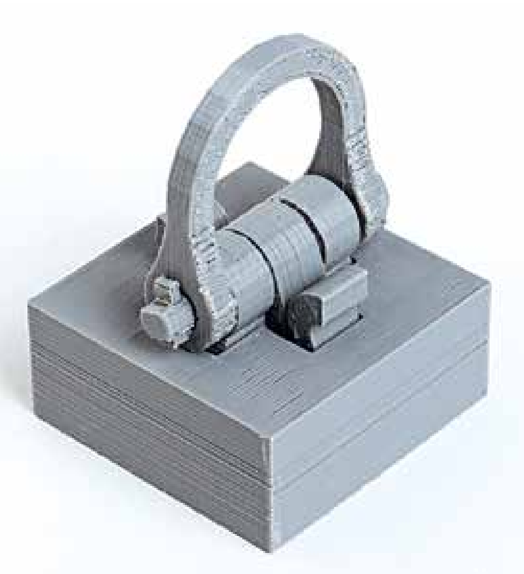


Fig. 6. *and* Fig. 7. *Model of the lewis assembled (left) and disassembled (below), made by the authors*

From the information supplied by Sangallo, it is possible to reconstruct and illustrate the central lewis, its components and its use (Figs 6–8). His labelling of the components with letters (*A*–*I*) is followed in our illustration in Figure 8. It is a five-key lewis, an elaboration of the standard three-key variety, and Sangallo showed it in a diagrammatic longitudinal section with two inverted wedges (*C* and *D*) inserted first and a straight-sided shim (*A*) dropped down between them. Along the tranverse section, this central key (*A*) expands out at the bottom in a wedge. As an afterthought, Sangallo sketched out the standard central key of a three-key lewis (labelled *K*), which is not included in the assembly, but is presented for comparison to *A*, as Sangallo explained in the adjacent note (see the appendix, page 53, D4). To secure the shim (*A*) on this axis, two identical smaller shims (*B*) slide down on the larger shim's transverse sides. The small diagram at the top of the page explains the relationship of the larger shim (*A*) to the smaller ones (*B*), and the annotation directs the reader to arrange the pieces as indicated. The next group of parts (*G, H, I*) connect the keys to the lifting bar by way of the horseshoe. A horizontal bolt (*G*) fastens the keys to the horseshoe (*H*) via sockets in the wedges

https://doi.org/10.1017/arh.2023.3 Published online by Cambridge University Press

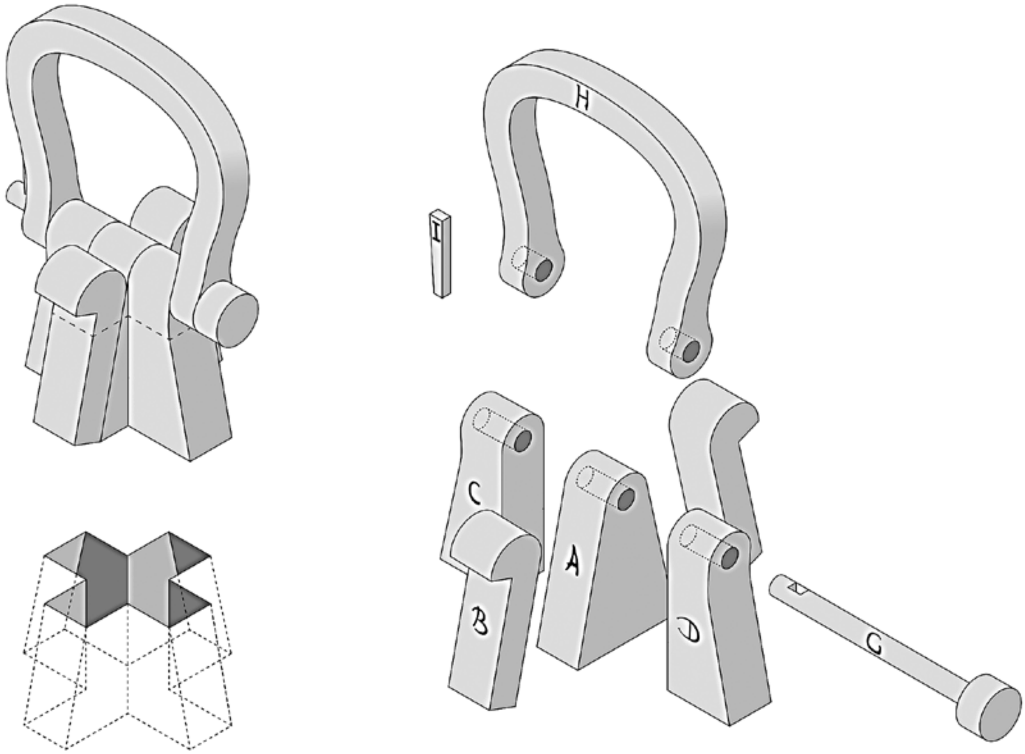


Fig. 8. *Diagrammatic view by the authors of the lewis and its cruciform cutting*

(*C* and *D*) and the shim (*A*), and is locked into place by a linchpin (*I*). As with Sangallo's textual discussions of Vitruvius elsewhere on this page, any written explanation of the assembly process is made redundant by the illustrations.

LEWISES AND THE WEIGHT OF HISTORY

Lewises were used all over the Greek and Roman world, although textual references to them are scant. Vitruvius's cryptic description of *ferrei forfices* — literally 'iron scissors' or 'iron tongs' — almost certainly refers to a different type of device: lifting tongs, or forceps, that hinged in the middle and tightened when winched.[17] Hero of Alexandria's *Mechanica*, written in the first century CE but known only from a ninth-century Arabic translation by the scholar Qusṭā ibn Lūqā, describes two types of device.[18] The first is the three-key lewis, which was common to Roman building projects, and the second is an earlier type made from a single trapezoidal piece of iron that had to be dropped into an opening of uniform width with a wedge-shaped slot for a securing pin at the side. This earlier device is well attested to on the coast of Asia Minor (mostly in Ionia and Caria) from the fourth century BCE, but was little used by Hero's time.[19] The Alexandrian scholar's reference to

https://doi.org/10.1017/arh.2023.3 Published online by Cambridge University Press

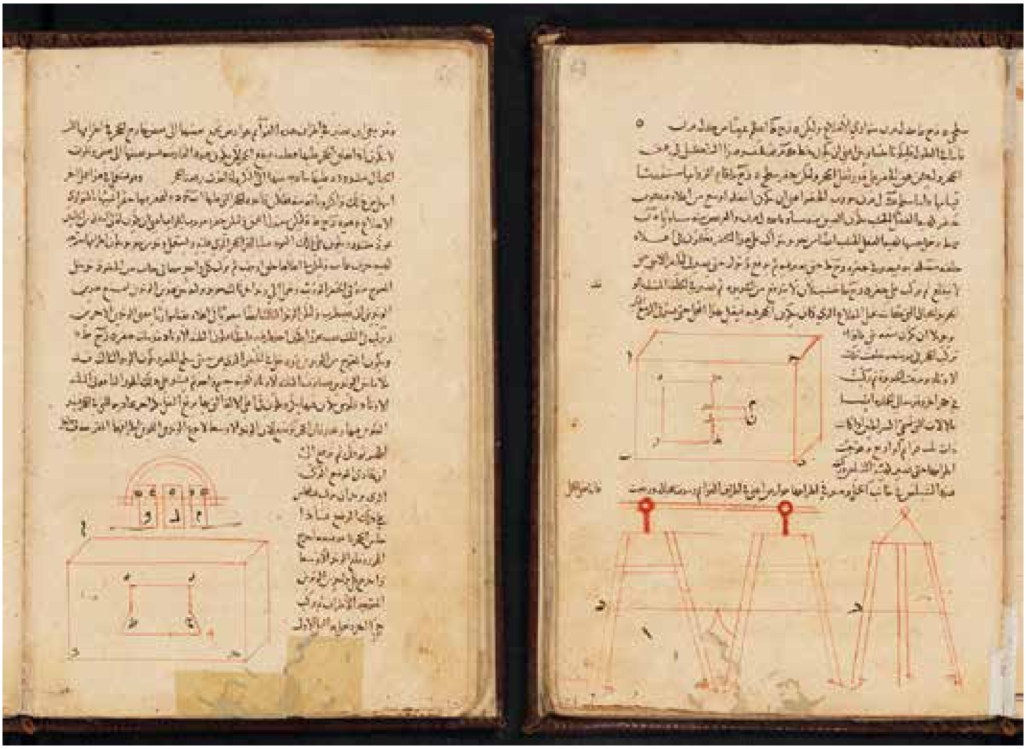


Fig. 9. *Discussion and illustration of lifting devices by Qusṭā ibn Lūqā in the ninth century, after Hero of Alexandria in the first century (Leiden University Libraries)*

a mostly obsolete lifting device suggests the ancestry of the more elaborate type of lewis then in common use. With particular variants becoming dominant in different periods and regions, Hero's account provides insight into how the original conception of the tool led to later developments and coexisting but varied forms.

Hero's *Mechanica* was originally accompanied by illustrations, although the drawings in the Arabic manuscript have suffered in fidelity as a result of their repeated copying (Fig. 9).[20] The text describing the multi-part lewis contains more than a dozen alphabetic references to two diagrams. In one of these diagrams, the lewis's constituent parts are labelled in much the same way as they are in Sangallo's drawing. Hero, however, principally used letters in the manner followed by Greek geometers in referring to polygons in a two-dimensional plane, specifying the perimeter of the top of a stone block as ΑΒΓΔ and that of the aperture for the lewis as ΕΖΗΘ. He was verbose in his description — extolling the importance of iron that was neither too hard nor too soft, and explaining the shapes of the components of the lewis and the sequence of inserting and removing them — but he needed drawing to express a principle that he struggled to put into words: that the cutting for the lewis needed to be precisely aligned over the stone block's centre of mass.

Sangallo was a serious scholar of Vitruvius and was preparing his own illustrated edition of the text for publication, so he would have known of Vitruvius's *ferrei forfices*. He probably did not know of Hero and his diagrams, even though he was familiar with Arabic tools and instruments, including astrolabes. He was nevertheless like Hero in being faced with a complex technical matter, which he dealt with in a similar way. Both architects used labelled diagrams and both focused on the same issues in their analyses, especially the need to align a lewis over the centre of mass. This principle, and the necessity of combining text and image to express it, was at the heart of Sangallo's investigation.

The lewis that Sangallo drew on his sheet has been described in the literature as an ancient metal lifting device found at St Peter's, which was being rebuilt to his design at the time that he made the drawing.[21] This notion must be set aside. Lifting devices were removed from blocks after their setting and only one complete example of an ancient lewis has ever been discovered.[22] What must still be considered is whether Sangallo's coverage of the lewis is documentary in nature — that is to say, does the drawing represent a modern lewis, left over from an earlier stage in the sixteenth-century construction at St Peter's? Or is it an attempt to reverse-engineer a possible lewis that would fit a cruciform slot? Or is the drawing instead a pure invention, an erudite extension of a known technology, in the form of a three-dimensional knot of interlocking wedges, that is more like a puzzle than a handy tool? Or, finally, does it show a viable possibility for a modern-day lifting device?

OLD ST PETER'S IN FRAGMENTS

Sangallo's lewis drawings are legible but ambiguous documents. For all the effort that he put into depicting a lewis that was functionally feasible, he never clarified whether the device was his discovery or his invention. Moreover, in his note that identifies the 'great square capitals of St Peter's', he did not specify whether he meant the capitals of the old basilica or the new one, a distinction that may have been obvious to him but is not any more. The drawings include no measurements that might help identify the capitals in question. We should not necessarily assume that Sangallo found any lewises, or even lewis sockets, at the site of old St Peter's and simply recorded what he saw. However, he was interested, on occasion, in the technical aspects of ancient buildings — studies of rain channels and metalwork appear among his drawings — and he could have regarded a five-key cruciform lewis socket as a prosaic but noteworthy feature. According to this logic, his discussion of the lewis would essentially be archaeological, providing an illustration of an item of historical technology. Although lewis sockets are typically obscured in complete buildings, the ruins of Rome provided an opportunity to inspect stone surfaces exposed through decay and collapse, and to study lewis cavities when the cavities were visible.[23] A capital with a cross-shaped socket would have sparked Sangallo's curiosity at any site, but if such a capital were seen at St Peter's, as Sangallo states it was, then it would have demanded his professional attention.

By 1542, Sangallo had served as first architect of the new basilica for over twenty years since assuming the task of bringing cohesion to a chaotically conceived project. He had begun work there as a carpenter and assistant draughtsman under Bramante in the first decade of the sixteenth century, before being promoted to deputy architect

Fig. 10. *Circle of Maarten van Heemskerck, drawing of Bramante's Tiburio (altar housing) during the construction of new St Peter's, Rome,* c. *1535 (Stockholm Nationalmuseum)*

under Raphael in 1516. When Raphael died suddenly in 1520, Sangallo took charge, leading the construction until his own death in August 1546. During this tumultuous time, multiple schemes coexisted. Remnants of the old church not yet demolished stood alongside the results of previous building campaigns led by Sangallo's predecessors that were far from completed, as can be seen in a drawing from the 1530s (Fig. 10).[24]

As the new basilica went up, Renaissance artists and architects documented fragments from the old one coming down.[25] They drew pieces of stonework for a variety of reasons, some utilitarian and others much less so. Such drawings provide a useful context for interpreting Sangallo's graphic analysis of the lifting device, and his drawing may indeed be the result of such an encounter. Some architectural stones from old St Peter's were treated as works of sculpture. An Ionic capital from the building with a particularly vivid graphic afterlife appears in a print by Diana Mantuana, made from a drawing by her husband, the architect Francesco da Volterra, and published in Rome in 1576 (Fig. 11).[26] Several architects had already admired this capital as it appears in many drawings, including one by Antonio da Sangallo and another by his brother Giovan Battista da Sangallo.[27] The capital was a marvel: the spiral of its volute was decorated with a flowering acanthus with leaves of ever-diminishing size. Mantuana's print focuses on this virtuosic passage of carving rather than on the capital as a whole,

https://doi.org/10.1017/arh.2023.3 Published online by Cambridge University Press

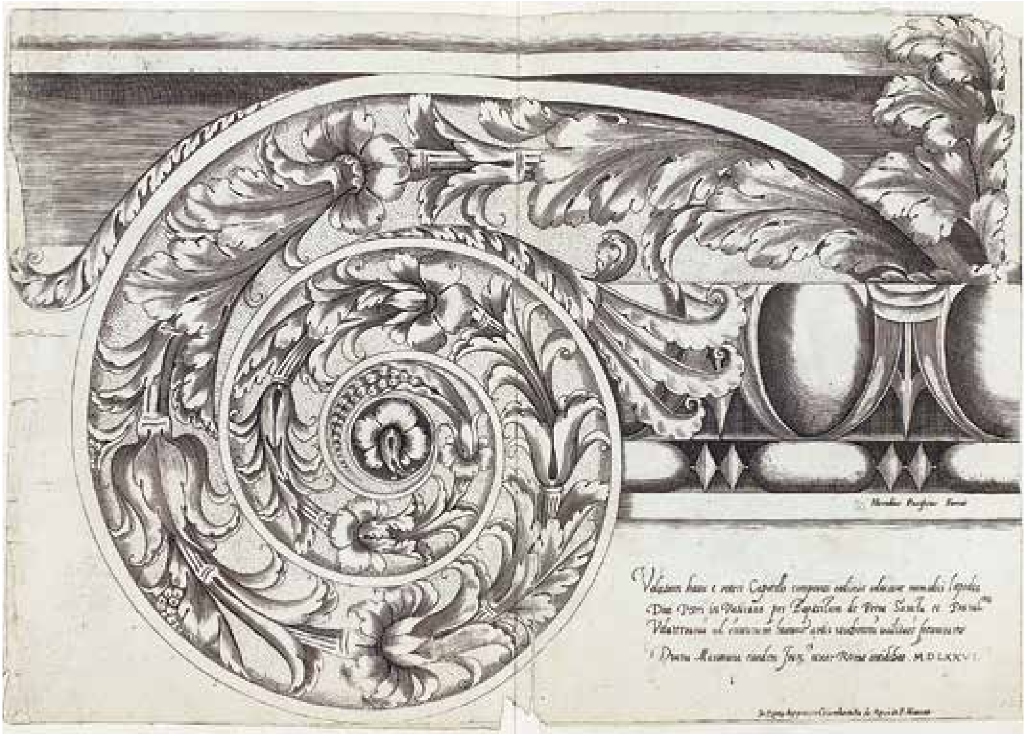


Fig. 11. *Diana Mantuana (Diana Scultori), volute of an Ionic capital from old St Peter's, Rome, engraving of 1576 after Francesco da Volterra from the* Speculum romanae magnificentiae *(British Library)*

and treats the fragment as an exemplary pictorial subject.[28] Yet, despite the veneration it received, the capital found no place in the new basilica.

Other architectural fragments from the old basilica were esteemed enough to be incorporated into the new one. The distinctive spiral columns that surrounded the shrine of St Peter, many of which Gian Lorenzo Bernini reused for the tabernacles of the crossing piers, are among the easiest to identify and are also the most studied. The monolithic shafts of the 100 columns that lined the nave and aisles of the old basilica also presented opportunities for architects who worked on the site.[29] These columns, many of them with shafts made from semi-precious stone, were among the most prominent architectural features of the old basilica. Reusing the shafts saved valuable building material and knitted the history and tradition of the sacred site into the new church's fabric. From a design point of view, however, the shafts presented considerable obstacles. Their heights needed to be accommodated in their new settings, which is why Baldassare Peruzzi and Giovan Battista da Sangallo, who worked alongside Sangallo as site architects, both made careful surveys of them. Their surveys addressed the problem of how to reuse the shafts by recording them all in profile and to scale, identifying their materials and numbering them individually to identify their locations (Fig. 12). Sangallo, like Raphael and Bramante

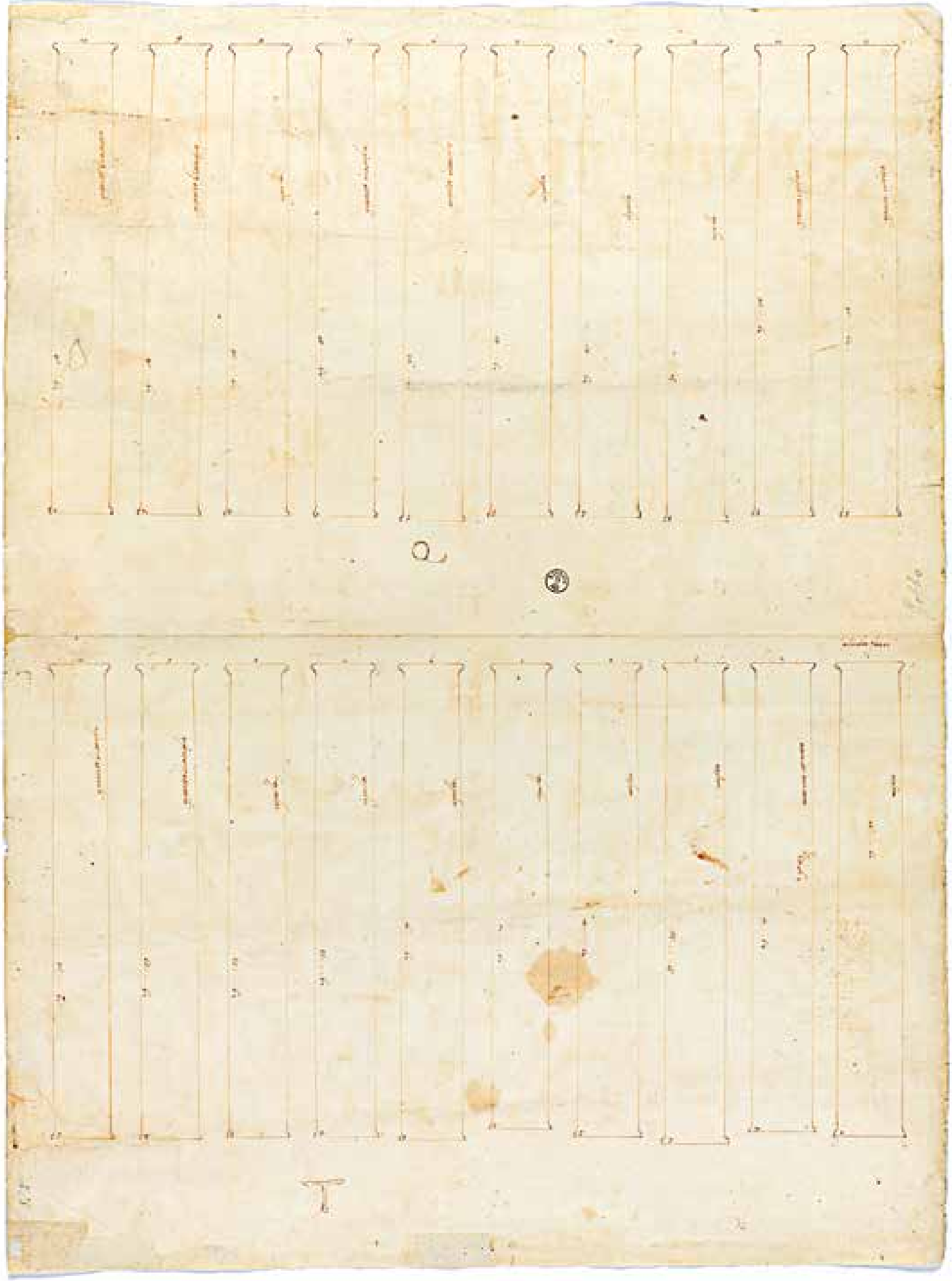


Fig. 12. *Giovan Battista da Sangallo, survey of column shafts at old St Peter's (Florence, Uffizi 1079A recto)*

https://doi.org/10.1017/arh.2023.3 Published online by Cambridge University Press

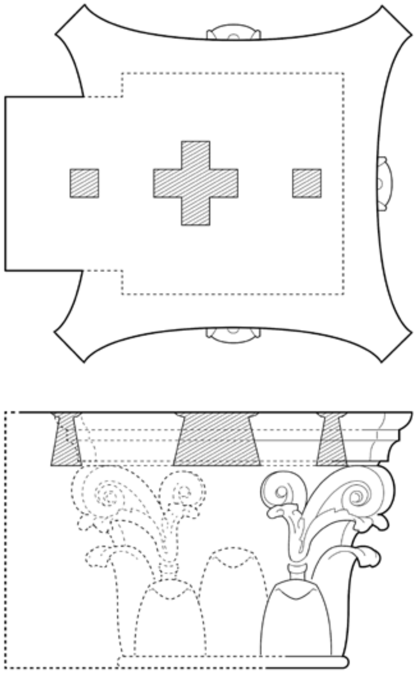


Fig. 13. *Plan and elevation of the pilaster capital by the authors*

before him, developed designs that made inventive use of the shafts, and the evidence suggests that he treated them with care. He eventually incorporated some of them into the new ambulatories he began constructing, although these were then eliminated in Michelangelo's subsequent changes to the building's design.

During Sangallo's time at St Peter's, dealing with redundant material on the site was an integral part of working on the new basilica, both logistically and intellectually. To make progress, Sangallo had to solve the problem of what to do with the large stones already there. Whether he planned to reuse or remove them, he had to get them out of the way. This circumstance could have been what drew his attention to the matter of the lewis. It is implausible that he found an intact ancient lewis in one of the capitals of the old basilica because, as already noted, lewises were removed from their sockets during construction so that subsequent blocks could be laid above. In some instances, lead pourings have been found in lewis sockets, which seem to be the overflows from setting dowels into the top surfaces of stones and so are sure indicators that the iron lifting tools had been removed. It is still possible that Sangallo found on the site an intact lewis that was modern, perhaps dating from Bramante's years. He kept drawings that survive of the wood centring that Bramante erected to construct the main dome, so it is plausible that he found an example of recent building technology on the site worth recording.[30] More likely is that he found lewis sockets in a stone and then, on paper, reconstructed the device that would have fitted the sockets. The idea that Sangallo was recreating something he determined to have existed is implied by the phrase he wrote near the lewis drawing: 'in order to find out how to use it, it is necessary to remake it as

https://doi.org/10.1017/arh.2023.3 Published online by Cambridge University Press

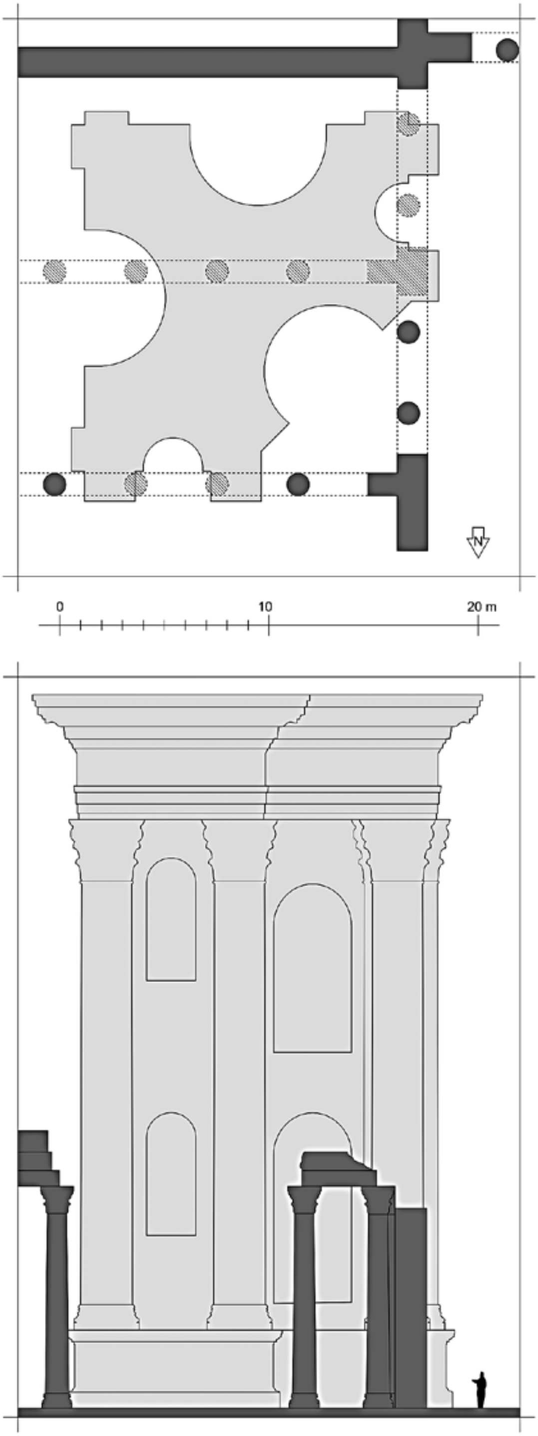


Fig. 14. *Plan and elevation by the authors of the southeast pier of the crossing of St Peter's Basilica, as depicted in the c. 1535 drawing (Fig. 10)*

https://doi.org/10.1017/arh.2023.3 Published online by Cambridge University Press

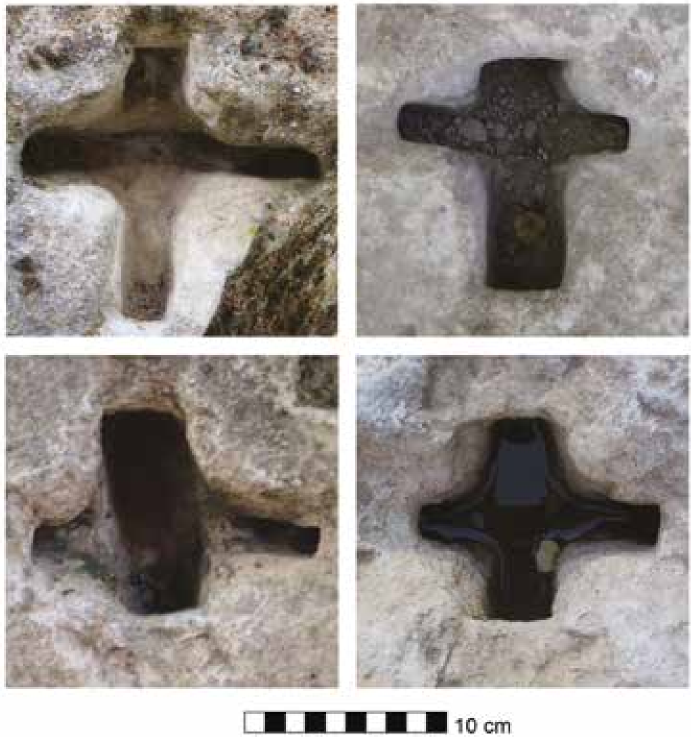


Fig. 15. *Ancient blocks with superimposed lewis cuttings from different phases of construction, photographs by Philip Stinson (courtesy of the New York University Aphrodisias Excavations)*

it is marked here below' ('bisognia trovare come se adoperare come refarlo stessi così come è segniato qui apresso').

The search to find the capital Sangallo drew should begin with the old building. His drawings of the capital of a Corinthian pilaster, which can be reconstructed more fully (Fig. 13), show it twice in plan with a flaring abacus and the spur of the attached wall on one side, with one of them recording the square plan of the capital's bottom surface in outline as well. A partial elevation gives the silhouette of a canonical capital (two tiers of acanthus leaves, a caulis from which spring a corner volute and helix, and an abacus with a cavetto and ovolo). The central fleuron is absent in this elevation, but is sketched on one of the plans at upper left. Old St Peter's had large Corinthian pilasters that appear to fit the bill, on T-shaped piers where the colonnades of the aisles terminated at the perpendicular colonnades screening off the transept (Fig. 14).[31] On the left side of the drawing from the 1530s (Fig. 10), one of the old Corinthian pilasters is visible, although dwarfed by the southeast pier of the new crossing rising up behind it. These pilaster capitals were hardly small: the columns in the aisles and transept of the old St Peter's were 4.5–5.5 ft in diameter. At this scale, a pilaster capital of the dimensions sketched by Sangallo could have weighed as much as 10 metric tons, warranting careful attention in lifting. In the left foreground of the drawing in Figure 10, the top half of a large Corinthian pilaster capital lies on its side, and this is conceivably from one of these pilasters, but it has no cuttings indicated on its top surface.[32]

It is possible that Sangallo saw a cruciform cavity on the St Peter's site that has a very different explanation. In ancient masonry construction, after blocks were set into position and lewis keys were removed, additional cavities were cut for dowels, which sometimes overlap the earlier lewis cutting.[33] When buildings were modified or blocks reused, new lewis cuttings might be needed, and these cuttings could overlap in a cruciform shape because they also needed to be set over the capital's centre of gravity (Fig. 15).[34] In cross-shaped cavities produced in this manner, it is sometimes possible to distinguish two cutting phases because of differences in depth and width. Shallower cuts tend to be older, made before the top of a block was levelled off in situ, and deeper cuts newer, made after the levelling. One block from Hierapolis in Phrygia has three overlapping lewis cuttings from more than one phase of repair which together form a modified cross shape.[35] Moving large blocks could require more than one lewis cutting, and sometimes repairs or reuse involved a different number of lewises than initial construction. For example, an Ionic column capital from the Temple of Artemis at Sardis has cuttings for six lewises which were produced in two phases: two (of Hero's second lewis type) from the original Hellenistic construction phase and four (of Hero's first lewis type) from a Roman remodelling phase.[36]

It appears at least possible, therefore, that Sangallo came across an ancient capital with a layered construction history. If so, this capital could have had two separate phases of cuttings for standard three-key lewises: one phase with three lewises in alignment (perhaps a later phase), and another phase with just one lewis set perpendicularly over the block's centre of gravity. Sangallo could then have conflated these cuttings into a single design. From a palimpsest in stone of successive building phases, he could thus have sought to reconstruct a unitary work of ancient ingenuity.

Today, architectural historians and archaeologists often overlook lewis sockets, for several reasons: they are difficult to measure and document, and often difficult to differentiate from other cuttings made during transport and construction.[37] Yet Sangallo was in the ideal position to recognise the potential use of these sockets because he was in charge of moving heavy stones around the building site. Unlike other architects at St Peter's — Bramante, Raphael and Peruzzi — Sangallo was not a painter, as many historians have pointed out.[38] He was unlikely to disassociate the design of an order from its consequences in masonry. It is those material consequences that connect Sangallo's lewis to his Vitruvian studies.

THE LEWIS AND THE MACHINE PORTRAIT

Sangallo's drawing of a five-key lewis also responds to an unusual challenge. It would be possible to make a fully symmetrical lewis for a cruciform socket, one with four identical wedges slotted in through the aperture and an additional shim slotted last into the centre. The challenge arises from two implicit operating principles. First, the lifting force must be applied to the wedge-shaped keys: pulling the central shim alone will disassemble the lewis. Second, rather than have a rigid junction between the lewis and the rope in tension, it is preferable, as Sangallo realised, to have a joint that was articulated by means of a pin and horseshoe, so that the block might be rocked along an axis to aid final positioning (see Fig. 6). As Sangallo worked out the problem on paper, he included an additional explanatory diagram of a T-shaped lewis in the upper-right

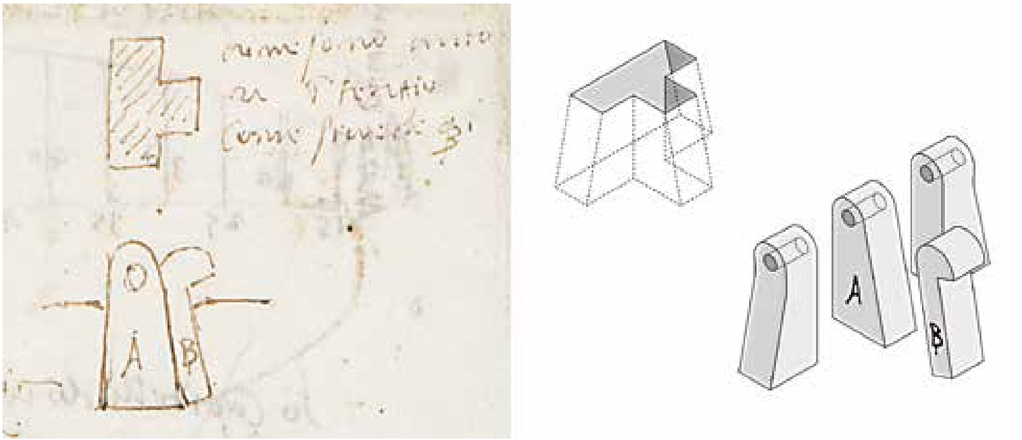


Fig. 16. *Antonio da Sangallo, diagram of a T-shaped lewis (detail of Uffizi 826A verso, Fig. 3) and a visualisation of it by the authors*

corner of the page which illustrates how a standard three-key lewis might be expanded to include just one extra perpendicular wedge (Fig. 16). Sangallo's diagram shows a T-shaped aperture with an accompanying section drawing depicting two elements: a wedge (labelled *A*) and a shim (labelled *B*). This drawing does not represent a complete lewis or even a fully formed concept, but instead offers an intermediate stepping stone as Sangallo untangled the puzzle of building up from the familiar three-key lewis to fill a cavity with wedges on two perpendicular axes.

Sangallo did not study the lewis in isolation: he drew it in the context of the carved masonry capital block that it was designed to move. The projecting abacus depicted in the drawings of the capital indicates that the lewis could be used without disturbing the monumental block's sculpted surfaces. It could thus be used to lift blocks that could not be easily lifted in other ways. Whether the triple-lewis configuration was for lifting a capital from old St Peter's or one for the new building is immaterial to the main point: it could have been designed for either — or for both. In masonry construction, the larger the block, the greater the likelihood that it could not be moved and positioned by ropes and cords alone. Blocks moved without lewises often required further cutting after placement to remove the bosses used for ropes.[39] In drawing his St Peter's capital, Sangallo was imagining how building with old and new architectural components could follow a single system that was preferable for both.[40]

With his exploration of his imagined lewis, Sangallo was also informed by a long line of Renaissance architects and artists who sought to elevate machines from the merely functional to the realm of creativity. The rise of the 'machine portrait' over the fifteenth and sixteenth centuries has been delineated by Paolo Galluzzi, who described how simple machines came to be ever more complex and machinery became a subject for art.[41] This lineage was developed in copybooks, in which architects studied each other's drawings of machines.[42] Sangallo participated in this visual tradition, copying drawings of lifting devices by Mariano di Jacomo Taccola (1381–1453/58) and Buonaccorso Ghiberti (1451–

https://doi.org/10.1017/arh.2023.3 Published online by Cambridge University Press

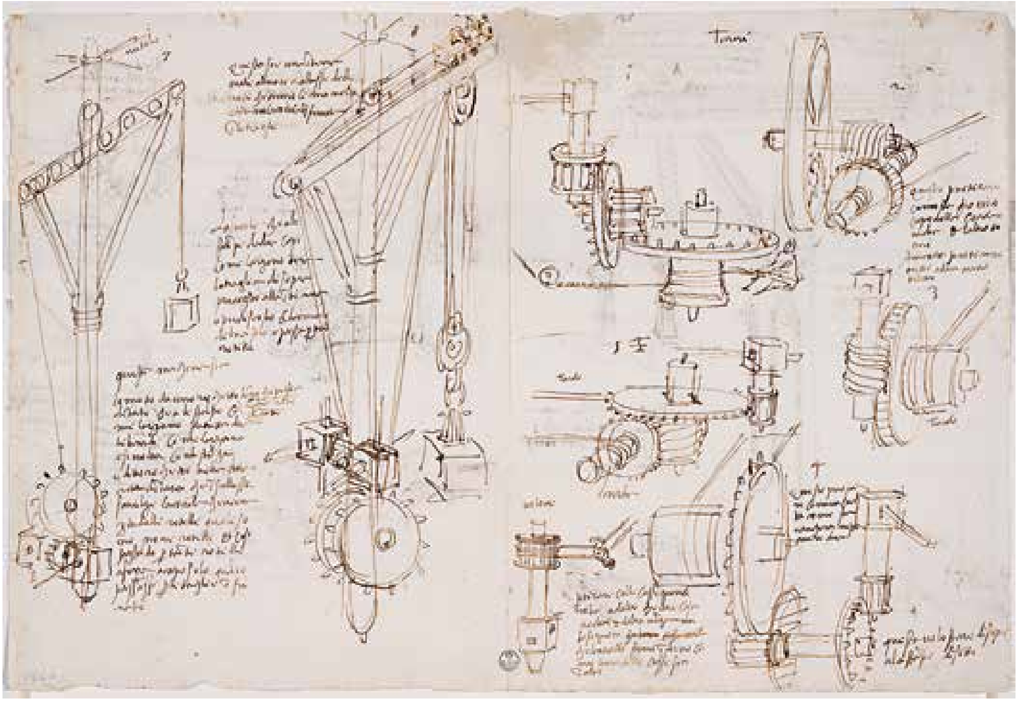


Fig. 17. *Antonio da Sangallo the Younger, studies of a crane and other lifting devices (Florence, Uffizi 1449A verso)*

1516), among others. Some of his studies of travelling cranes and hoists (Fig. 17), possibly made in preparation for a treatise on the subject, have their antecedents in drawings by Francesco di Giorgio.[43] The lewises that appear in studies by other practitioners are often the necessary mechanisms that connect hoisting devices to their loads, but on occasion the lewis could even be a drawing's principal subject. Leonardo da Vinci, who drew hundreds of machines for lifting stones, gave the lewis some special scrutiny. On a sheet of studies of masonry construction, he drew both a lewis and various types of forceps, and experimented with how to combine two pairs of forceps for lifting a stone block (Fig. 18).[44] Both Leonardo and Sangallo were thus exploring how heavy blocks could be lifted into precise locations with ever more complex devices. In this sense, Sangallo's drawing of the cruciform lewis could be considered to have a complexity bordering on the superfluous.

CONCLUSION

Sangallo drew the lifting device to address specific problems on a building site where he had to contend with the old and new basilicas at once — practical concerns that could not be separated from his artistic ambitions. The relationship between the lifting device and the other studies on the sheet demonstrates how these two objectives intertwined. In his

https://doi.org/10.1017/arh.2023.3 Published online by Cambridge University Press

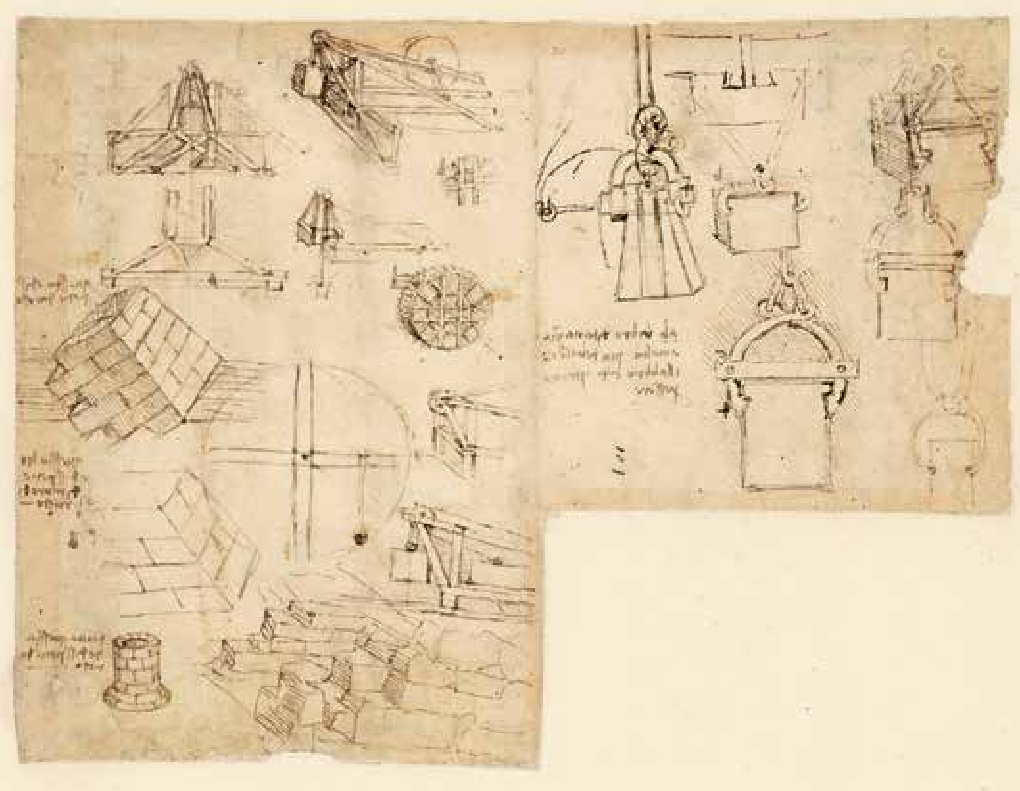


Fig. 18. *Leonardo da Vinci, studies of masonry construction and lifting devices including a lewis and forceps*, c. *1514–15 (Milan, Biblioteca Ambrosiana, Codex Atlanticus)*

Vitruvian studies, Sangallo sought to develop systems that could accommodate a wide spectrum of formal variations, just as, at St Peter's, he was wrestling to accommodate architectural fragments from different periods into a coherent whole. Following a similar line of thought, just as the proportions of columns needed to be adjusted as their scale increased, so too did the tools that were used to lift them. On this one sheet, Sangallo sought both to find common ground in the designing of capitals, streamlining Vitruvius's advice on the subject, and to address the subject of how very large capitals could be installed, which was with recourse to lewises of increasing complexity. When an architect rooted in the practicalities of stone masonry involved himself in the design of new capitals, the principles of their design and how they might be hoisted into place were never far from mind.

Lewises have been used for many centuries over a vast territory. Yet Vasari's story shows how Sangallo nevertheless could have associated the lewis with a specifically local history: Brunelleschi's supposed rediscovery of the tool amid the ancient ruins of Rome and his implied subsequent use of it to construct Florence's cathedral, the most ambitious construction project of the modern era. Galluzzi's term 'machine portrait' is

https://doi.org/10.1017/arh.2023.3 Published online by Cambridge University Press

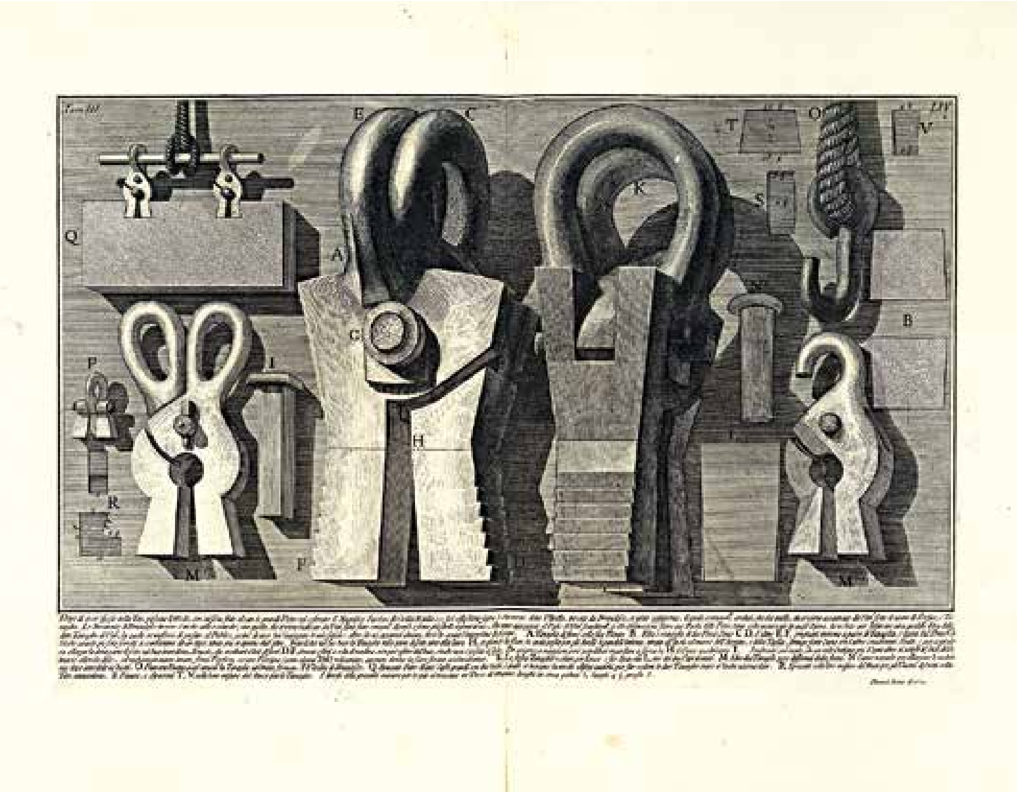


Fig. 19. *Giovanni Battista Piranesi, plate LIV from* Le antichità romane, *vol. 3, 1756, showing lewises and other lifting devices (Princeton University Library)*

evocative of how tools, machines and other technical devices can take on lives of their own. For Sangallo, inventing a new form of lewis was an opportunity to improve on a famous predecessor.

Sangallo was not the last architect to try to outdo the master with a bigger, better lewis. Giovanni Battista Piranesi, in his *Antichità Romane* of 1756, supplied his own interpretations of the *ferrei forfices* in Vitruvius, at the centre of a large print devoted to various types of lifting device (Fig. 19). Piranesi's illustration accompanied his discussion of the Tomb of Cecilia Metella and, in the print, he imagined the machinery and processes that the ancient Romans must have used to construct the monument, including the lewis. Piranesi referred to the lewis in the plate's caption as the instrument 'discovered by Brunelleschi' ('lo Stromento detto Ulivella, trovato da Brunelesco'), and showed a small version of it on the far left (indicated by the letter P); however, Brunelleschi's device is visually overpowered by his Vitruvian reconstructions.[45] No modern device, Piranesi seems to suggest, could surpass those of antiquity. Sangallo, in his drawings, engages in a parallel endeavour of antiquarian competition, seeking to expand and improve on lifting tools that had become indispensable by discovering new ancient models.

https://doi.org/10.1017/arh.2023.3 Published online by Cambridge University Press

APPENDIX

PAGE A

A1
Corintio
Jonicho
Dorico
Colonne

A2
Questi capitelli nascono l'uno
Dall'altro come se vede qui

A3
Jonicho
Capitello
Colonne

A4
In casa Porchari
presso alla Mi-
nerva

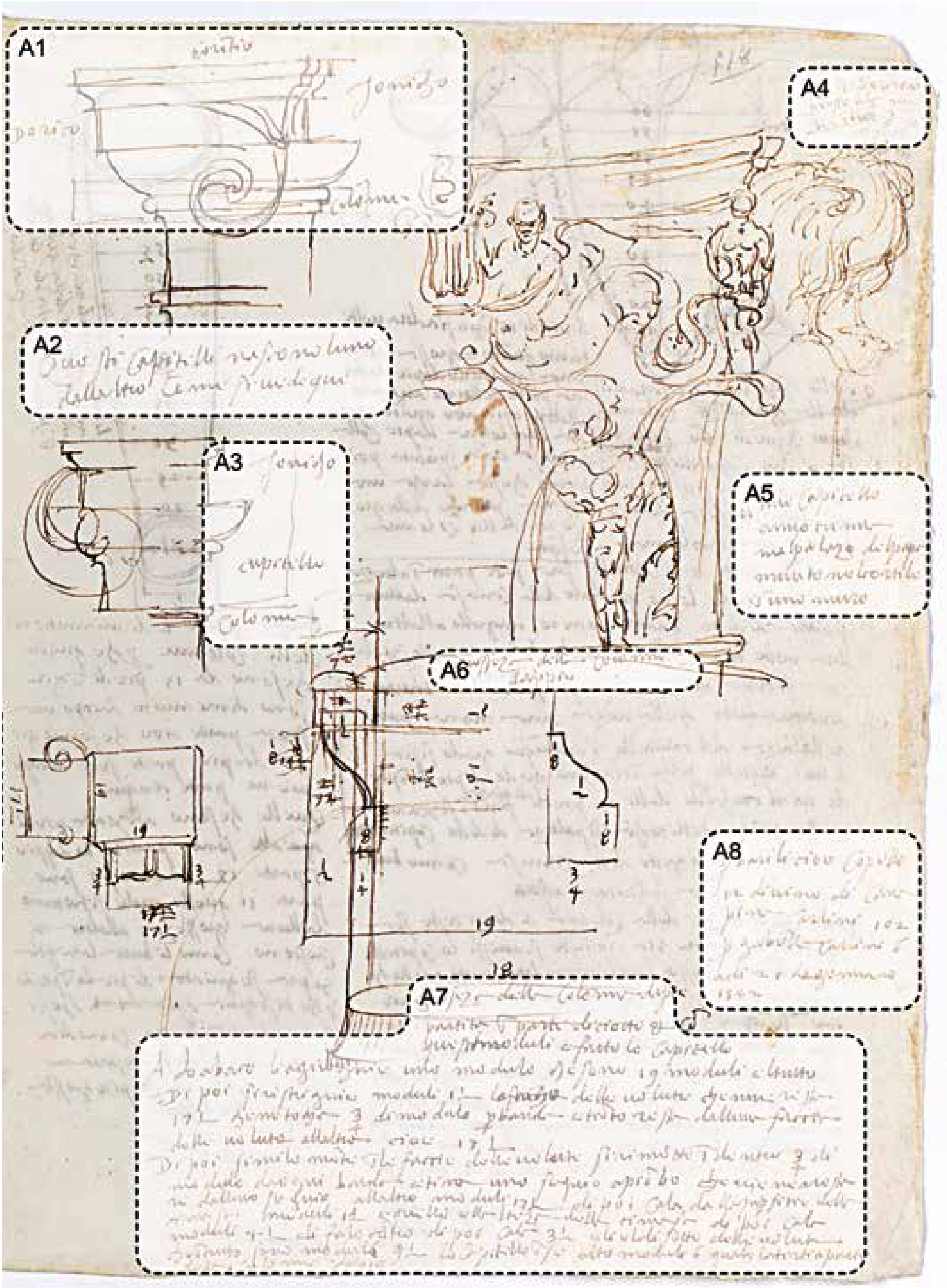
A5
Uno capitello
ànno trovato
nel palazo del papa
murato nel cortile
in uno muro

A6
Grosseze delle colonne
Dappiè

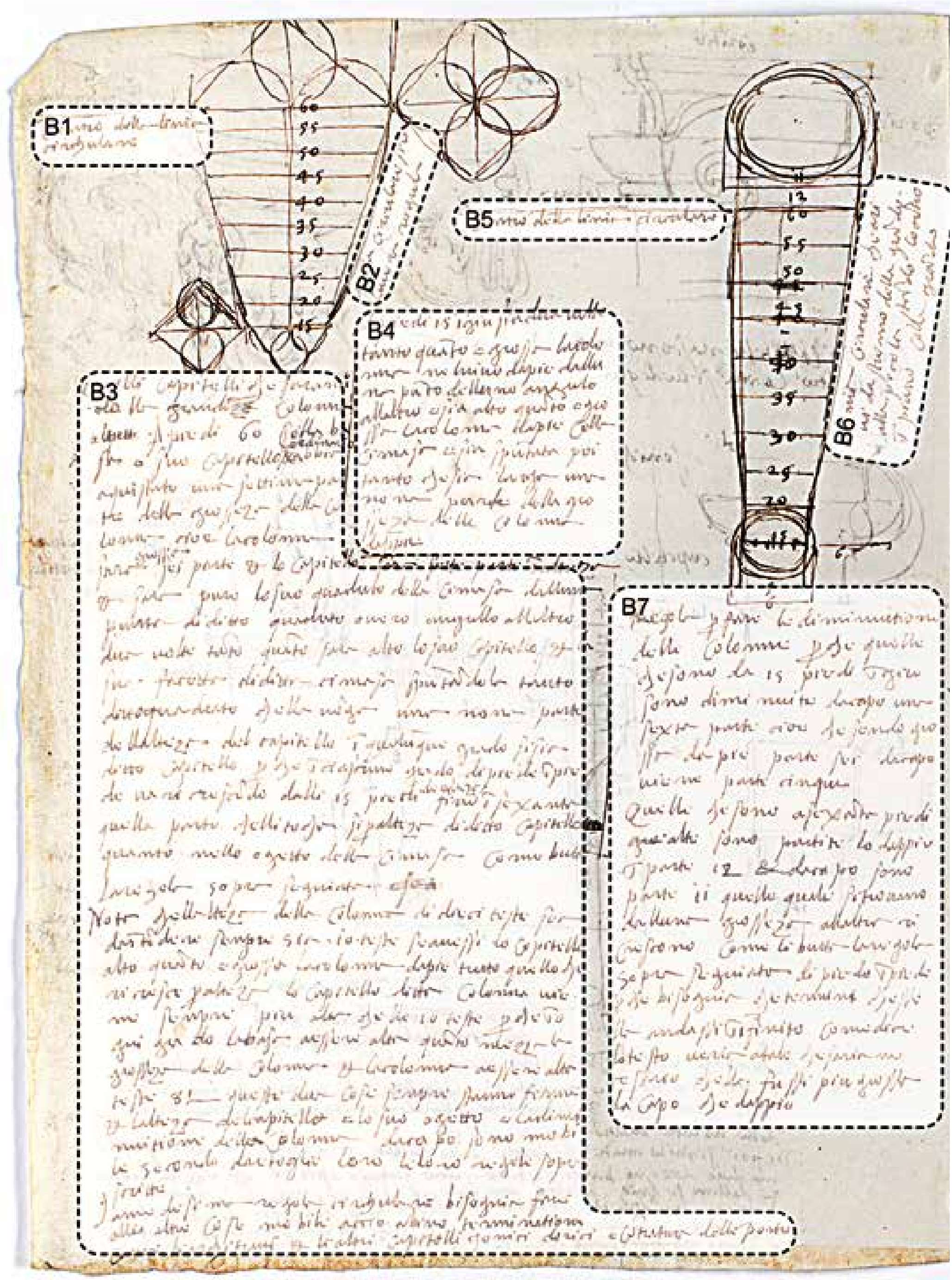
A7
Groseze delle colonne da piè
Partita in parte diciotto & con
questi moduli e fatto lo capitello
A lo abaco le agiugnie uno modulo che sono 19 moduli el tutto.
Di poi si ristringne moduli 1 1/2 lo fiancho delle volute che avi resta
17 ½ che ne tocha ¾ di modulo per bande e tanto resta dall'una faccia
delle volute all'altra cioè 17 ½.
Di poi simili mente in le faccie delle volute si rimette in dentro ¾ di
modulo da ogni banda e tira uno segnio a piombo che viene a resta-
re dall'uno segnio all'altro moduli 17 ½ di poi cala dalla supra facce della
cimasa moduli 1 ½ e quello delle [a]lteze della cimasa di poi cala
moduli 4 ½ e li facto centro di poi cala 3 ½ e l'è el di sotto delle volute
che in tutto sono moduli 9 ½ lo capitello in se altro moduli 6 quale la tertia parte
delle colonne da piè

A8
per barile cioè copelle
12 di vino di cana-
pine carlini 102
per gabelle carlini 6
adì 25 di gennaro
1542

https://doi.org/10.1017/arh.2023.3 Published online by Cambridge University Press



https://doi.org/10.1017/arh.2023.3 Published online by Cambridge University Press



https://doi.org/10.1017/arh.2023.3 Published online by Cambridge University Press

PAGE B

B1
Centro delle linee
circhulare

B2
questa circulare sera
lavera regula

B3
Quelli capitelli che saranno
delle grandi colonne
alte .A. piedi 60 colla ba-
se e suo capitello ordinario abbia
aquistato una settima par-
te delle grosseze delle co-
lonne cioè la colonna
sarà grossa sei parte etc. lo capitello sarà sette
parte in alteza
etc. sale puro lo suo quadrato della cimasa
dall'una
punta di detto quadrato overo a mezullo all'altro
due volte tanto quanto sale alto lo suo capitello
et le
sue facette di detta cimasa spuntandola tanto
detto quadrato che lla venga una nona parte
dell'altezza del capitello in qualunque grado si
sia
detto capitello perché in ciascuno grado di piede
in pie-
de va re crescendo dalli 15 piedi di alteza fino in
sexanta
quella parte che lli tocha si per alteza di detto
capitello
quanto nello ogetto della cimasa come butta
la regola sopra segniata.
Nota che ll'alteza della colonna di dieci teste
scen-
dente deve senpre sia 10 teste se avesse lo
capitello
alto quanto è grossa la colonna da piè tutto
quello che
ri-cresce per alteza lo capitello detta colonna vie-
ne senpre più alta che lle 10 teste perché in o-
gni grado la base à essere alta quanto mezza la
grosseza della colonna etc. la colonna à essere
alta
teste 8 ½ queste due cose senpre stanno secure
etc. l'alteza del capitello e lo suo ogetto e la dimi-
nuitione della colonna da capo sono mobi-
le secondo che togl[i]e loro le loro regole sopra
scritte.
La medesima regola cerchulare bisognia fare
alle altre cose mobili accio abino terminationi
come le architrave & li altri capitelli jonici
dorici e contrature delle porte

B4
A piede 15 in giù sia dua volte
Tanto quantò è grossa la colo-
nna nel vivo da piè dall'u-
no punto dell'uno angulo
all'altro e sia alto quanto è gro-
ssa la colona da piè colla
cimasa e sia spuntata poi
tanto che sia l'archa una
nona parte della gro-
sezza della colonna
da ppiè

B5
Centro della linea circulare

B6
Linea circulare che ari-
va da stremo della grande
alla picola stando lo contro
in piano colla grande

B7
Regole per fare la diminutione
delle colonne perché quelle
che sono da 15 piedi in giù
sono diminuite da capo una
sexta parte cioè che che sendo gro-
sse da piè parte sei da capo viene parte cinque.
Quelle che sono a sexanta piedi
alte sono partire lo doppio
in parte 12 & da capo sono
parte 11 quelle quale si trovano
dall'una grosseza all'altra ri-
crescono come le butta la regola
sopra segniata di piede in piede
perché bisognia che termini che sse-
lla andasse in infinito come dice
lo testo veria a tale che saria ne-
cesario che lla fusse più grossa
da capo che doppio

https://doi.org/10.1017/arh.2023.3 Published online by Cambridge University Press

PAGE C

C1
Altezza colonna

C2
Architravi

C3
2/3 della Colonna

C4
Lo Capitello doricho a piedi 15 sarà alto
quanto meza Colonna cioè sendo la ~~colonna~~
Colonna moduli 12 lo Capitello sarà alto
moduli 6 e quello di piedi 60
Lo Capitello sarà moduli
7 di 12 della gro-
seza della colonna

C5
questo sarà
alto colle volute moduli
10 Bisognia partirlo in mo-
duli 9 e distribuirlo come
l'altro e torna bene
Cose bisognia fare a ciascuno
in ogni suo grado

C6
Alli 15 piedi lo capitello
sarà alto quanto la colonna
è grossa doppia

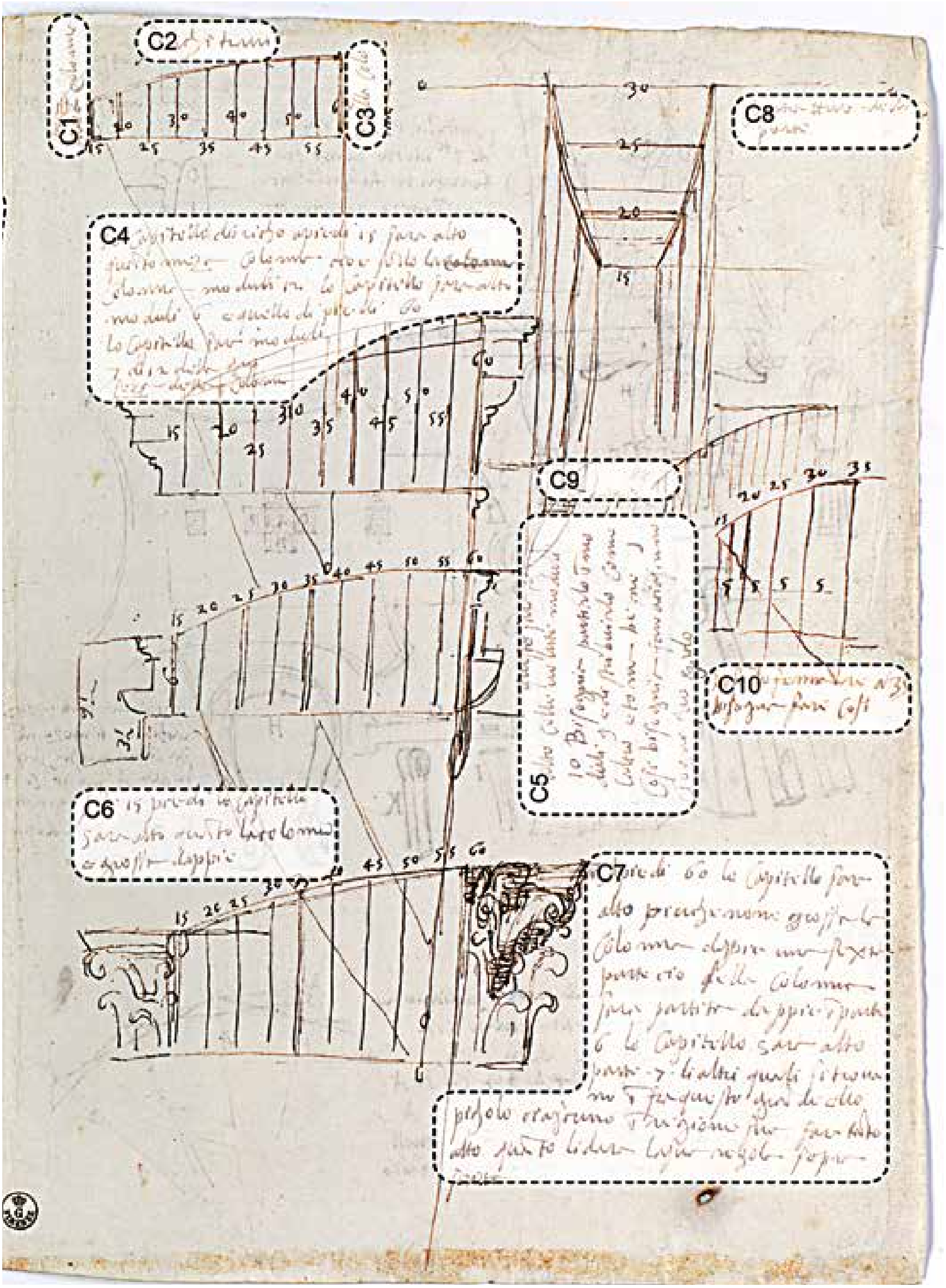
C7
A piedi 60 lo Capitello sarà
alto perché non è grossa la
Colonna da ppiè una sexta
parte cio[è] della Colonna
sarà partita da ppiè in parte
6 lo Capitello sarà alto
parte . 7 . li altri quali si trova-
no in fra questo grande e llo
picholo ciascuno in ragione sua sarà tanto
alto quanto li darà la sua regola sopra
scritta

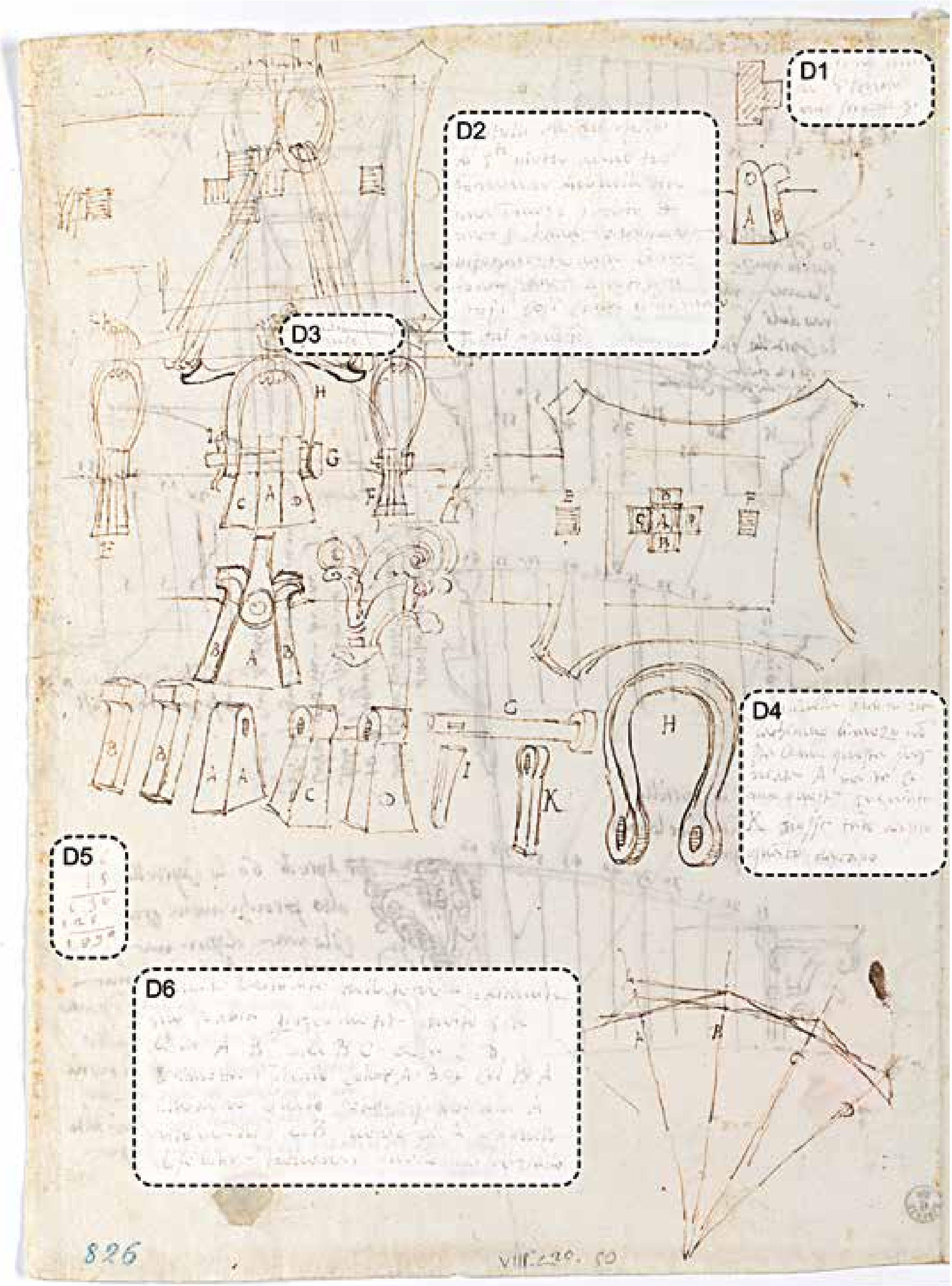
C8
Contrattura delle porte

C9
doppia

C10
Volendo fermare a 35
bisognia fare così

https://doi.org/10.1017/arh.2023.3 Published online by Cambridge University Press


C1
C2
C3
C4
C5
C6
C7
C8
C9
C10



https://doi.org/10.1017/arh.2023.3 Published online by Cambridge University Press

PAGE D

D1
tre ne sono ferratu-
re in tertio
come si vede qui

D2
Capitelli quadri grandi
Di S[an]to Pietro ànno tre
ferrature di livella cioè
una in mezo in crocie et
una per banda ordinaria
bisognia trovare come
se adoperare come refarlo
stessi così come è segniato
qui apresso

D3
Legnio

D4
per la livella ordinaria
la chiave di mezo non
sta come questa seg-
niata A ma sta co-
me questa segniata
K grossa tanto da piè
quanto da capo

D5
126
15

630
126

1890

D6
Per trovare la ritondità della terra e diametro
Suo si abia per geometr[i]e quanto sia
dallo A B e da B C & da C D
e si metta in piano colle A B & col B A
e vederò quanto se alza sopra alla A
ritornando da B verso la A e per quella
diferentia troverai quello vai cercando

ACKNOWLEDGEMENTS

The authors would like to thank Marisa Bass, Dario Donetti, Yaacob Dweck, Lynne Lancaster, Pamela O. Long, Carolina Mangone, Michele Mazeris, Bert Smith and Philip Stinson, as well as the two anonymous reviewers and the editorial team of *Architectural History*, particularly David Hemsoll, for their advice and expertise. Nicoletta Baldini provided invaluable assistance preparing the transcription of Uffizi 826A.

BIOGRAPHIES

Samuel Holzman is assistant professor of Greek architectural history at Princeton University. He leads the architectural research team of American Excavations Samothrace. Email: sholzman@princeton.edu

Carolyn Yerkes is associate professor of early modern architecture at Princeton University. She is the author of *Drawing after Architecture: Renaissance Architectural Drawings and Their Reception* (Marsilio, 2017) and the co-author, with Heather Hyde Minor, of *Piranesi Unbound* (Princeton University Press, 2020). Email: yerkes@princeton.edu

NOTES

1 Giorgio Vasari, *Le vite de'più eccellenti pittori, scultori ed architettori* (1568), ed. by Gaetano Milanesi, 9 vols (Florence: G. C. Sansoni, 1906), II, pp. 338–39: 'tolse tutte le collegazioni e di pietre e d'impernature e di morse; ed, investigando a tutte le pietre grosse una buca nel mezzo per ciascuna in sottosquadra, trovò esser quel ferro, che è da noi chiamato la ulivella, con che si tira su le pietre, ed egli lo rinnovò e messelo in uso dipoi. Fu, adunque, da lui messo da parte ordine per ordine, dorico, ionico e corintio; e fu tale questo studio, che rimase il suo ingegno capacissimo di poter vedere nella immaginazione Roma, come ella stava quando non era rovinata.' English translation from Giorgio Vasari, *Lives of the Painters, Sculptors and Architects* (1568), 2 vols, trans. by Gaston de Vere (New York: Everyman's Library, 1996), I, pp. 331–32).

2 Antonio Tuccio Manetti, *The Life of Brunelleschi*, ed. by Howard Saalman (University Park, PA: Pennsylvania State University Press, 1970).

3 For discussion of the machines Brunelleschi used in the construction of Santa Maria del Fiore, see Piero Sanpaolesi, *La cupola di Santa Maria del Fiore: Il progetto — la costruzione* (Florence: EDAM, 1977). The lewis detail of Sangallo's drawing is reproduced on p. 40.

4 For discussions of the sheet in terms of its recto and verso sides, see Pasquale Nerino Ferri, *Indice geografico-analitico dei disegni di architettura civile e militare esistenti nella R. Galleria degli Uffizi in Firenze* (Rome: Presso i principali librari, 1885), pp. 17, 29, 81, 131, 150, 161; Alfonso Bartoli, *I monumenti antichi di Roma nei disegni degli Uffizi di Firenze*, 6 vols (Florence: Bontempelli, 1914–22), VI, p. 66; Gustina Scaglia, 'U 826A *verso*', in *The Architectural Drawings of Antonio da Sangallo the Younger and His Circle, Volume 1: Fortifications, Machines, and Festival Architecture*, ed. by Christoph L. Frommel and Nicholas Adams (New York: Architectural History Foundation, 1994), pp. 148–49; Paola Zampa, 'U 826A *recto and verso*', in *The Architectural Drawings of Antonio da Sangallo the Younger and His Circle, Volume 2: Churches, Villas, the Pantheon, Tombs, and Ancient Inscriptions*, ed. by Christoph L. Frommel and Nicholas Adams (New York: Architectural History Foundation, 2000), pp. 154–56; Christoph Luitpold Frommel, 'Sangallo and Antiquity', in *The Architectural Drawings of Antonio da Sangallo the Younger and His Circle, Volume 3 A: Antiquity and Theory*, ed. by Christoph L. Frommel and Georg Schelbert (Turnhout: Brepols, 2023), p. 46.

5 All translations are by the authors, unless otherwise noted.

6 Paola Zampa, 'Dall'astrazione alla regola: Considerazioni in margine ad un disegno di Antonio da Sangallo il Giovane', *Bollettino d'Arte*, 46 (1987), pp. 49–62.

7 Manfredo Tafuri, 'Roma Coda Mundi: The Sack of Rome, Rupture and Continuity', in *Interpreting the Renaissance: Princes, Cities, Architects*, trans. by Daniel Sherer (New Haven and London: Yale University Press, 2006), pp. 169–70. See also Hubertus Günther, 'Serlio e gli ordini architettonici', in *Sebastiano Serlio*, ed. by Christof Thoenes (Milan: Electa, 1989), pp. 154–68.

8 Four sixth-century capitals, probably from the church of SS. Cosma e Damiano in the Roman Forum and now in Lyon, have eagles under their corner abaci which are remarkably similar to the one Sangallo drew,

except that they stand on garlands atop a basket rim and not on leaves. For these and other eagle capitals, see Federico Guidobaldi, 'Origine costantinopolitana e provenienza romana di quattro capitelli del VI secolo oggi a Lione', *Mélanges de l'École Française de Rome*: *Antiquité*, 101 (1989): pp. 317–64. On the eagle capital that Sangallo drew at the Casa Porcari, see Flavia Contatore, 'Melchiorre Passalacqua nella trasformazione delle case Porcari-Doria Pamphili nel rione Pigna', in *Roma borghese: Case e palazzetti d'affitto, II*, ed. by Elisa Debenetti (Rome: Bonsignori, 1995), p. 333.

9 There is a strong tradition of figural capitals within the Sangallo family: see, for example, Giuliano da Sangallo's capitals that incorporate decorative carvings of birds and nudes. See also Giovan Francesco da Sangallo's studies of Roman imperial capitals: Adriano Ghisetti Giavarina, 'U 1702A *verso*', in *The Architectural Drawings of Antonio da Sangallo the Younger and His Circle, Volume 3 A*, ed. by Frommel and Schelbert, p. 203.

10 Francesco Benelli, 'Antonio da Sangallo the Younger and the Making of the Ionic Capital', *Ædificare*, 2 (2017), pp. 95–117. Benelli also demonstrates that Sangallo continued his development of the Ionic order on another sheet (Uffizi 1189A). See also Francesco Benelli, 'Secondo Fra Giocondo: Antonio da Sangallo il Giovane e l'edizione di Fra Giocondo del 1513 del Metropolitan Museum of Art di New York', in *Giovanni Giocondo: Umanista, architetto e antiquario*, ed. by Pierre Gros and Pier Nicola Pagliara (Venice: Marsilio, 2014), pp. 53–68 (pp. 65–66).

11 The abacus has unusual proportions and Sangallo may have enlarged it for the sake of legibility.

12 Zampa, 'Dall'astrazione alla regola'; Zampa, 'U 826A *recto and verso*', in *The Architectural Drawings of Antonio da Sangallo*; Paola Zampa, '"Vole stare così Bastardato"', in *Materia, struttura e filologia: Nuovi contributi sull'architettura del Rinascimento*, ed. by Francesco Benelli (Rome: Accademia nazionale di San Luca, 2021), pp. 45–56; Pier Nicola Pagliara, 'Studi e pratica vitruviana di Antonio da Sangallo il Giovane e di suo fratello Giovanni Battista', in *Les Traités d'architecture de la Renaissance*, ed. by Jean Guillaume (Paris: Picard, 1988), pp. 179–206.

13 Vitruvius, *De architectura*, book 3, chapter 3, 11–13; book 3, chapter 5, 8–9.

14 For a brief discussion of this diagram, see Gustavo Giovannoni, *Antonio da Sangallo il Giovane*, 2 vols (Rome: Tipografia Regionale, 1959), I, p. 17. In an apparently unrelated calculation written above the diagram, Sangallo multiplies 126 by 15.

15 Pliny, *Naturalis historia*, book 2, 108. For ancient geographic calculations, see Reviel Netz, *A New History of Greek Mathematics* (Cambridge: Cambridge University Press, 2022), pp. 233–39.

16 Christopher Drew Armstrong, *Julien-David Leroy and the Making of Architectural History* (London: Routledge, 2012), pp. 68–86.

17 Vitruvius, *De architectura*, book 10, chapter 2, 2.

18 Hero of Alexandria, *Mechanica*, book 3, chapters 6–8. See Bernard Carra de Vaux, 'Les Mécaniques ou L'élévateur de Héron d'Alexandrie, publiées pour la première fois sur la version arabe de Qost â ibn Lûqâ, et traduites en français', *Journal Asiatique*, ser. 9, 2 (1893), pp. 491–93, reprinted in F. Sezgin, ed., *Hero of Alexandria in the Arabic Tradition: Texts and Studies*, Natural Sciences in Islam, 38 (Frankfurt: Institute for the History of Arabic-Islamic Science at the Johann Wolfgang Goethe University, 2001), pp. 293–95; Aage Gerhardt Drachmann, *The Mechanical Technology of Greek and Roman Antiquity* (Copenhagen: Munksgaard, 1963), pp. 103–06.

19 Poul Pedersen, 'The Ionian Renaissance and Alexandria Seen from the Perspective of the Karian-Ionian Lewis', in *Labraunda and Karia; Proceedings of the International Symposium Commemorating Sixty Years of Swedish Archaeological Work in Labraunda*, ed. by Lars Karlsson and Susanne Carlsson (Uppsala: Uppsala Universitet, 2011), pp. 365–88.

20 Leiden University Libraries, Or. 51:1, Qusṭā ibn Lūqā after Hero, *Mechanica*, 63–64.

21 Scaglia, 'Uffizi 826Av', in *The Architectural Drawings of Antonio da Sangallo the Younger and His Circle, Volume 1*, pp. 148–49.

22 Friedrich Drexel, 'Das Kastell Faimingen', in *Der obergermanisch-raetische Limes des Römerreiches. Lieferung XXXV aus Band VI B Nr. 66c* (Heidelberg: Verlag von O. Petters, 1911), pp. 1–112 (46, Taf. VI, 21); William Aylward, 'Lewises in Hellenistic and Roman Building at Pergamon', in *Bautechnik im antiken und vorantiken Kleinasien: Internationale Konferenz 13.–16. Juni 2007 in Istanbul*, ed. by Martin Bachmann (Istanbul: Ege Yayinlari, 2009), pp. 309–22 (p. 310, Figs 1–2).

23 Plenty of ancient Roman building sites still have visible construction marks, including clamp cuts and lewis, forceps and dowel sockets: for a photographic survey, see Giuseppe Lugli, *La tecnica edilizia romana con particolare riguardo a Roma e Lazio*, 2 vols (Rome: G. Bardi, 1957).

24 Stockholm Nationalmuseum, NMH Anck 637. See Richard Krautheimer, 'Some Drawings of Early Christian Basilicas in Rome: St. Peter's and S. Maria Maggiore', *Art Bulletin*, 31 (1949), pp. 211–15.

25 For an overview, see Dale Kinney, 'Spolia', in *St. Peter's in the Vatican*, ed. by William Tronzo (Cambridge: Cambridge University Press, 2005), pp. 16–47.

26 Paolo Bellini, ed., *L'opera incisa di Adamo e Diana Scultori* (Vicenza: N. Pozza, 1991), p. 214, cat. 29.
27 Mark McDonald, *The Print Collection of Cassiano dal Pozzo: Architecture, Topography and Military Maps* (London: Harvey Miller 2019), p. 493. On Antonio da Sangallo's drawing (Uffizi 32A), Giovan Battista da Sangallo's drawing (Uffizi 1804A) and others of the capital, see Kinney, 'Spolia', pp. 38–39.
28 Diana Mantuana has often been known as Diana Scultori since the twentieth century. On the printmaker and her print, see Evelyn Lincoln, 'Making a Good Impression: Diana Mantuana's Printmaking Career', *Renaissance Quarterly*, 50 (1997), pp. 1101–04, and Evelyn Lincoln, *The Invention of the Italian Renaissance Printmaker* (New Haven and London: Yale University Press, 2000), pp. 111–45.
29 Lex Bosman, *The Power of Tradition: Spolia in the Architecture of St. Peter's in the Vatican* (Hilversum: Verloren, 2004), pp. 29–46.
30 Uffizi 226A; on this drawing see Christoph Luitpold Frommel, 'Donato Bramante, Project for the Centering of the Pier Arches, ca. 1509', in *The Renaissance from Brunelleschi to Michelangelo: The Representation of Architecture*, ed. by Henry A. Millon and Vittorio Magnago Lampugnani (Milan: Bompiani, 1994), p. 609, cat. 297.
31 Krautheimer, 'Some Drawings', pp. 211–12. Our Figure 14 is redrawn from Alberto Carlo Carpiceci and Richard Krautheimer, 'Nuovi dati sull'antica basilica di San Pietro in Vaticano, parte II', *Bulletino d'Arte*, 95 (1996), pp. 1–84 (pp. 26–27, Figs 30, 32).
32 Two-piece Corinthian capitals had their heyday between the late second century BCE and the late second century CE: see Seth G. Bernard, 'The Two-Piece Corinthian Capital and the Working Practice of Greek and Roman Masons', in *Masons at Work*, ed. by Robert Ousterhout, Renata Holod and Lothar Haselberger (Philadelphia, PA: University of Pennsylvania, 2012), p. 13.
33 For overlapping dowel and lewis cuttings, see Günther Stanzl, 'Das Ptolemaion von Limyra', in *L'Architecture monumental grecque au IIIe siècle a.C.*: *Mémoires*, 40, ed. by Jacques des Courtils (Pessac: Ausonius éditions, 2015), p. 191; Günther Stanzl, 'Werkspuren und Bautechnik am Ptolemaion von Limyra: Eine ostlykische "Bauhütte" im Dienst der Ptolemäer?', in *Werkspuren: Materialverarbeitung und handwerkliches Wissen im antiken Bauwesen: Diskussionen zur Archäologischen Bauforschung*, 12, ed. by Dietmar Kurapkat und Ulrike Wulf-Rheidt (Regensburg: Schnell + Steiner: 2017), pp. 215–16.
34 We are grateful to Bert Smith and Phil Stinson for bringing to our attention examples of overlapping lewis cuttings at Aphrodisias.
35 Tommaso Ismaelli and Sara Bozza, 'Olivelle a Hierapolis di Frigia: Analisi tecnologica e morfo-dimensionale dei dispositivi di sollevamento tra Augusto e Alessandro Severo', *Thiasos: Rivista di archeologia e architettura antica*, 11 (2022), p. 327, Fig. 5 (no. 42).
36 Howard Crosby Butler, *Sardis Volume II: Architecture, Part I. The Temple of Artemis* (Leyden: Late E. J. Brill, 1925), pl. XVI.
37 Aylward, 'Lewises', p. 311, n. 12.
38 See, for example, Paola Zampa, '"Questo tempio è di opera dorica": Il dorico, da Antonio da Sangallo il Giovane a Palladio', *Annali di Architettura*, 29 (2017), pp. 127–34 (p. 130).
39 Peter Rockwell, *The Art of Stoneworking: A Reference Guide* (New York: Cambridge University Press, 1993), p. 176.
40 Following Aylward's premise that 'builders probably avoided unnecessary complexity and kept variation at a minimum' ('Lewises', p. 312).
41 Paolo Galluzzi, *The Italian Renaissance of Machines*, trans. by Jonathan Mandelbaum (Cambridge, MA: Harvard University Press, 2020).
42 Daniela Lamberini, 'Macchine da cantiere nella Firenze del primo Cinquecento: L'eredità brunelleschiana tra "imitatio", re-invenzioni e continuità', in *La difficile eredità: Architettura a Firenze dalla repubblica all'assedio*, ed. by Marco Dezzi Bardeschi (Florence: Alinea, 1994), pp. 106–21.
43 See Gustina Scaglia in *The Architectural Drawings of Antonio da Sangallo the Younger and His Circle, Volume* 2, pp. 224–25; Paolo Galluzzi, 'Antonio da Sangallo il Giovane e Francesco di Giorgio', in *Prima di Leonardo: Cultura delle macchine a Siena nel Rinascimento*, ed. by Paolo Galluzzi (Milan: Electa, 1991), pp. 246–47.
44 Milan, Biblioteca Ambrosiana, Codex Atlanticus, f. 38r/10v-b. See Wolfgang von Stromer, 'Brunelleschis automatischer Kran und die Mechanik der Nürnberger Drahtmühle: Technologie-Transfer im 15. Jahrhundert', *Architectura*, 7 (1977), pp. 163–74. Leonardo drew another sheet of studies of both lewises and lifting tongs in Codex Madrid I, MS 8937, f. 22r.
45 Peter N. Miller, 'Piranesi and the Antiquarian Imagination', in *Piranesi as Designer*, ed. by Sarah E. Lawrence (New York: Smithsonian, Cooper-Hewitt, National Design Museum, 2007), pp. 123–37 (pp. 128–34).