SEEING THE INVISIBLE. ANALYTICAL DRAWINGS BY CONSTRUCTION HISTORY PIONEERS. RESEARCH FIELD OVERVIEW

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Abstract
Introduction: The history of construction is a discipline that began to take shape in the mid-18th century and throughout the 19th century. We as researchers need to pay particular attention to how drawing facilitated progress during this period. This article attempts to provide an overview of the above, which is currently lacking. **Methods:** In this study, two lines of investigation intersect: the history of construction and the history of drawing, specifically drawing for scientific and technical representation. The main goal is to identify the sources (authors, lines of investigation) relevant to this field, as well as to characterize the role of drawing in the authors' work, and to describe the spread of drawing as nonverbal thinking. **Results:** We have identified a number of relevant authors, described their lines of research, and listed the functions fulfilled by drawing in each case. The functions include: hypothesizing about hidden structures, visualizing the construction processes, and providing a virtual definition for elements that make up a vault. We also review how some drawings acted as a visual model of the constructive reality, or how parallel drawings served as a reflection of the different buildings' size and scale. **Discussion**: This overview adjusts some points of reference for a general picture. For having a complete understanding of the subject, it will be necessary to identify more sources and to extend the geographical scope of this search in the future. There is still much research to be done on the spread of the drawings in question.

Keywords
History, drawing, construction, analysis.

Introduction

The history of construction is a relatively young discipline. Since 2000 — when the first International Congress on Construction History was held at the Madrid School of Architecture (ETSAM) — the history of construction has been consolidated through national and international congresses (in London, Cottbus, Paris, Chicago, Brussels, and soon in Lisbon), as well as through journals and scientific societies, as a well-defined and growing academic field.

However, this field owes a fundamental debt to the research carried out in the past. As this past research was fragmented, one of the vital research branches in the history of construction is its historiography, which teaches us about the methods, hypotheses, and tools used by those who can be considered its pioneers. Here, we have focused on studying the response presented to that question by those architects, scholars, or engineers who, throughout the 18th and 19th centuries (often conditioned by the «ideological» preference of one style of architecture over others), tried to understand the construction procedures of a particular period.

One of the methodological problems they had to face was how to make the invisible visible. It was a challenge to recreate the construction procedures of the past, often hidden, or known only from ruins, or completely lost because they were based on perishable materials. So was shedding light on the geometric principles and rules of defining the size of structural elements.

What role did drawing play in the resolution of this problem? Should we assume that drawing only reflected verbal thinking? Or was it, on the contrary, an indispensable conceptual tool that implied another form of autonomous thought, which made it complete? And in that case, what degree of autonomy did it have with respect to verbal thinking?

In a broad sense, the subject has been in the air for a long time, waiting for its formulation. The contribution of drawing to the birth of a neighboring discipline, the history of architecture, which emerged in France in the 19th century, was addressed in a seminal work by S. Talenti (2000). It was an exciting invitation to do the same in the field of the history of construction. The importance of non-verbal thinking in engineering was highlighted even earlier in E.S. Ferguson's groundbreaking study (1992). However, we still lack a study that would offer a comprehensive and complete answer to these questions in our field. This article proposes a method for approaching these questions and provides a provisional response: a synthesized, panoramic vision resulting from the application of the method.

Methods

Given the breadth of the question and the scarcity of previous works, the course of action from the very beginning was to review a series of monographs that, gradually, could shape an answer, demonstrated throughout different congresses and symposiums on the history of construction.

Over the course of this research — in which two lines intersect: the history of construction and the history of drawing for scientific and technical representation — a general method for a systematic study has emerged. It consists of a series of steps that have been followed in this article.

The first step is to identify relevant authors and texts. In many cases during the period in question, while the studies purported to review the architecture of a specific period, their sources were «masked» as a chapter or a section. The next step is to identify and characterize the types of constructive problems that they studied (and addressed graphically) and the methods that they used to solve such problems. Finally, we examine the role and characteristics of the drawings that were used. To identify the images capable of operating as «non-verbal thinking», we have considered two hypotheses.

On the one hand, the nascent history of construction, just as other disciplines, would benefit from the innovations that took place in drawing for scientific or technical purposes during the 18th and 19th century. In our research, we have tried to identify how construction historians applied this type of drawing — which we will be calling «operational» drawing — and the concrete results this led to.

On the other hand, we could say that the drawing process acted as a «conceptual mental frame» that encouraged further studies. A drawing is not a mere reproduction of reality. It is the result of intellectual labor that selects, highlights, abstracts, or eliminates specific sensory evidence of the object that it represents. In this way, it shows us a substitute for reality, meant to direct our attention to certain aspects of reality. Bearing this in mind, we have sought to single out those constructive analysis drawings that would perform this function in a particularly efficient way.

This article aims to illustrate how this method can shape this field of research and guide new studies. As it is based on a limited selection of monographs, it is not exhaustive. What follows is a concise overview of the results, indicating some relevant authors, the lines of research that they followed, and the functions assigned to drawing in each case. For an in-depth discussion of each specific topic mentioned in the article, the reader should consult the materials in this article's References section.

Roman Construction: Piranesi's Virtual Hypothesis

This review will begin by taking a look at Piranesi's work. His name inevitably evokes associations with the intensely emotional, almost oppressive impression made by his prints with scenes from Ancient Rome, which so convincingly convey the idea of the power to build on an enormous scale.

But, as we are captivated by the chiaroscuro of his engravings, we might forget that Piranesi (1756) also had a genuine interest in understanding the structures that he depicted (D'Amelio and De Cesaris, 2011; Pizzo, 2011). A good number of Piranesi's drawings boldly aimed to analyze the construction procedures. Some of these drawings were a kind of «virtual hypothesis», which revealed his perception of both what he could observe in situ and of the foundations or other inaccessible parts.

Piranesi would rely on previous «ready-made» visual representations of construction procedures that he could find in the Vitruvius editions. It is a known fact that the interpreters, editors, and translators who dealt with Vitruvius from the Renaissance onwards only had a text that was often ambiguous and difficult to interpret and lacked images. The engravings in some illustrated editions, such as those by C. Cesariano (1521) or G.A. Rusconi (1590), showed hypotheses about a specific construction process, which was probably based on generalized observations of existing ruins. By manipulating and integrating these images, Piranesi achieved if not a faithful reconstruction, then at least a plausible one (Giron Sierra, 2005) (Fig. 1).

These and other plates by Piranesi, depicting Roman construction, were very influential. Until the last third of the 19th century, they were practically the only source of authority on Roman construction. This form of sharing and distributing drawings has gone quite unnoticed. These drawings reappeared in the hands of other authors, often stripped of expressiveness to give them an aseptic and technical appearance (Giron Sierra, 2015).

Sometimes such image migration and manipulation were related to a change in the way of organizing information, which, in turn, was a response to an epistemological shift. Many of J.-B. Rondelet's plates on Roman construction are an example of this. Piranesi's images, which belonged to a conceptual framework where «knowing» meant showing many layers of information about a specific architectural object, had to be integrated into a new framework where «knowing» meant separating and comparing these layers with others from different sources. Piranesi's «palimpsests» had to be selected, reordered, and dressed into a neutral scientific language to place them into those thematic tableaux (Fig. 2).

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Reassembling the Greek Temple by Visualizing it under Construction: Pieces, Devices, and Movements

The authors of the generation that followed Piranesi opened two new fronts of study: Greek architecture (which Piranesi had underestimated, considering it inferior to Roman architecture) and Gothic architecture. But in fact, these two types of architecture required very different approaches from whoever wanted to document their history.

The first publications on Greek architecture mainly captured its picturesque aspect (Houel, 1782; Le Roy, 1758). However, the next generations would discover «in situ» that neither the forms nor the proportions of the temples were as they expected, not fitting the Vitruvian theory. It became clear that it was imperative to «learn to see» and to divorce one's mind from preconceived images. From J. Stuart and N. Revett (1762) onwards, drawing would become a vital tool for refining perception throughout the 19th century. Researchers would progressively improve drawing techniques to meticulously capture any subtleties and to accurately describe the curves and proportions and even the use of color (Pennethorne and Robinson, 1878; Penrose, 1851).

Initially, the study of construction and its representation would not be a central theme.

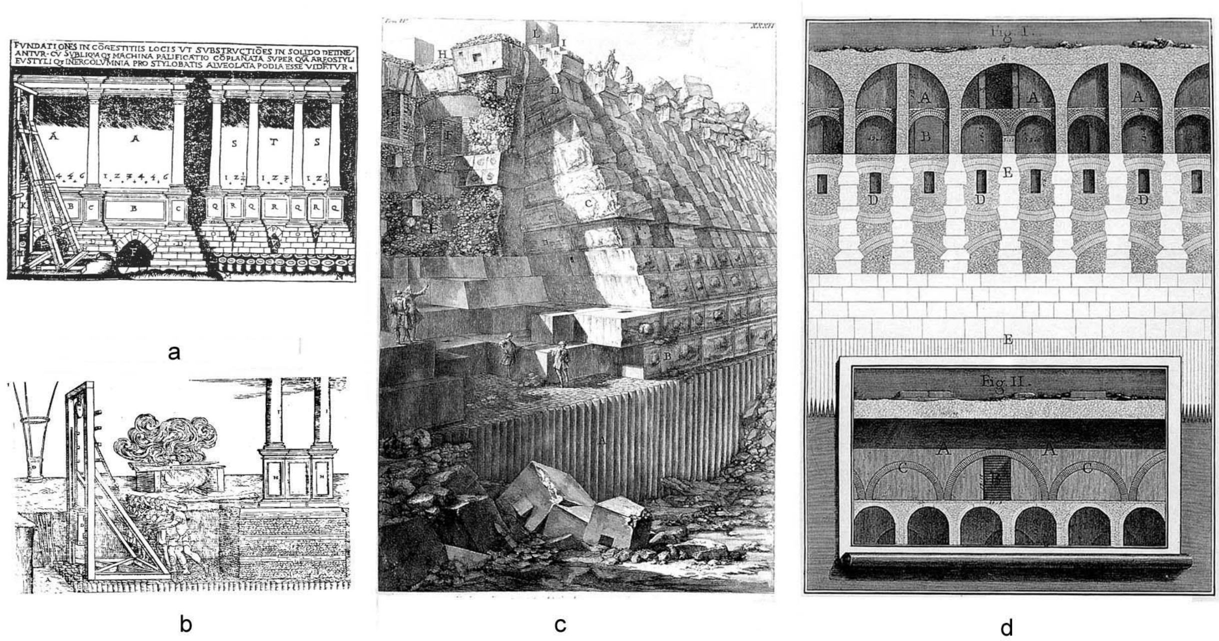


Figure 1. Roman construction and its invisible substructures. Graphic interpretations based on Vitruvius: a — Cesariano (1521); b — Rusconi (1590); c, d — construction of Marcellus' theater according to Piranesi (1756)

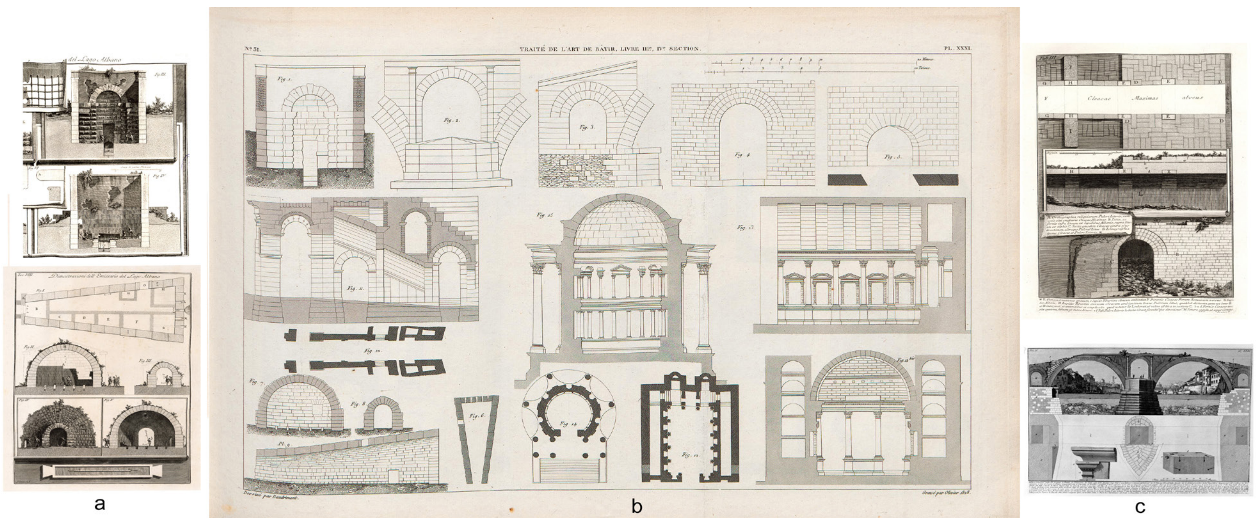


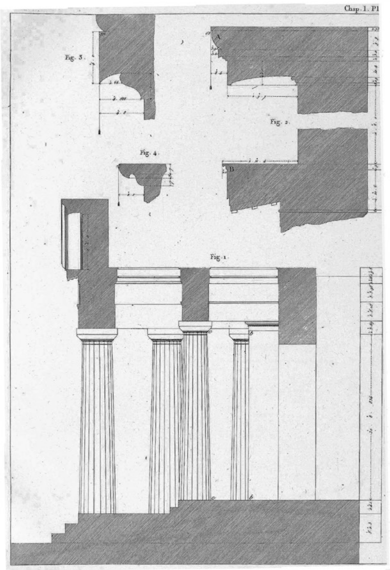
Figure 2. Left: a — Piranesi's Emisario del Lago Albano (1764). Right: c — Piranesi's (1761) Cloaca Maxima, d — Piranesi's (1756) Ponte Fabricio. Center: b — incorporation of those images in Rondelet (1830–1832)

The evolution of Greek temples seemed to be more relevant to the search for formal and optical improvements rather than to the optimization of their constructive resolution. Even so, there were various interesting comments and drawings, where rigorous surveys (both in elevation plan and in section) reflected not only the proportion and measurements of a temple, but also each joint, assembly piece, or degree of finish (Cockerell et al., 1830; Penrose, 1851; Wilkins, 1832) (Fig. 3).

Here, unlike in Roman construction, the problem of «seeing inside» the solid buildings was, in a way, solved. The temples' scattered remains made it possible to examine and reasonably describe the individual pieces (bases, columns, drums, lintels) that made them up. The real challenge was different: to recompose, so to speak, the building's carcass, and to reveal, as far as possible, how the various pieces were assembled and why they had been added (for example, for seismic resistance).

On the other hand, it was possible to reveal the stages and process of construction in a much more reliable way. There were even places where multiple stages of the construction process were evident. For example, in Selinunte, where a Greek temple seemed to have been suddenly abandoned mid-construction, the operations of extracting, transporting, lifting, and putting in place could be reconstructed easily. This led to the creation of drawings detailing how a particular piece was moved and set in its position (Cockerell et al., 1830) or comprehensive diagrams showing all the machinery involved in the temple construction in action (Hittorff and Zanth, 1870) (Fig. 4).

While the definition of the constructive section of the temple advanced with each new exploration,



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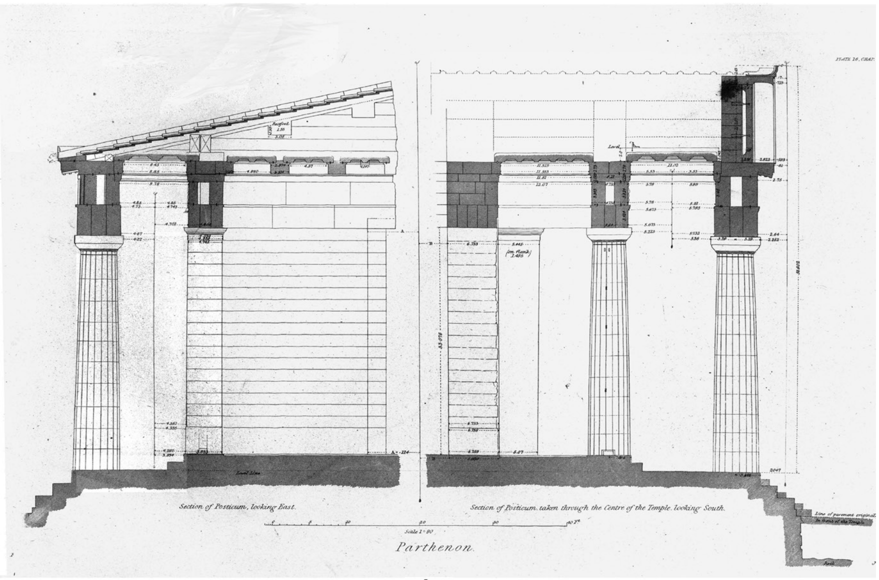
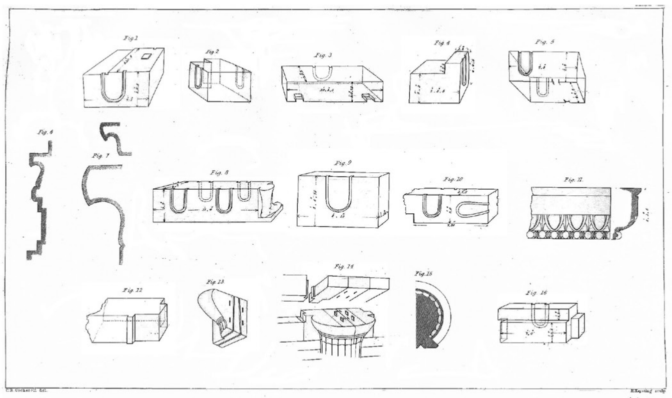


b

Figure 3. Left: a — early surveys of Greek temples, focused primarily on their forms and proportions: J. Stuart and N. Revett (1762, 1825). Right: b — an additional description of constructive features, mid-19th century (Penrose, 1851)



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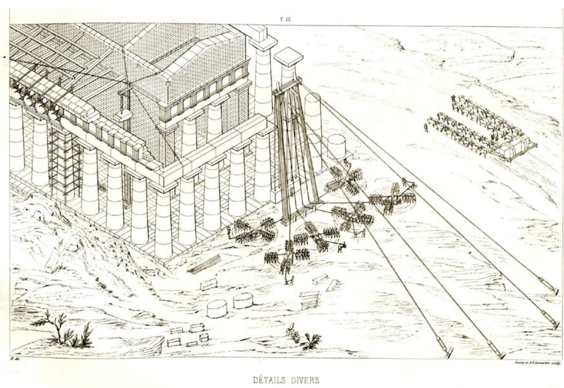

b

Figure 4. Three-dimensional views required by the visualization of ashlar pieces for reconstructing the lifting and joining operations and eventually the entire construction process: a — perspectives in (Cockerell et al., 1830); b — axonometric projection of Temple S in Selinunte under construction (Hittorff and Zanth, 1870)

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the interest in showing these techniques would lead to the occasional use of axonometry, a system that, despite being not much used in architectural drawing at the time, would allow for measuring and defining the three-dimensional form of each component. This trend is notable in some plates and illustrations (Blouet, 1833; Choisy, 1873; Hittorff and Zanth, 1870; Loviot, 1880; Wilkins and Gaudy, 1832), but at the end of the century, it gave way to recollections like those in (Perrot and Chipiez, 1898) (Fig. 5).

Gothic Construction: Robert Willis' Scientific Approach to Seeing the Invisible

The study of Gothic architecture was a more complicated task, as one could not count on a text of Vitruvius' authority to help with studying the building. To cope with this, the scholars of the first decades of the 19th century adopted a strategy that was rather reminiscent of the methods employed by naturalists. It was a matter of identifying, cataloging, and dating the building elements (windows, buttresses, pinnacles, pillars), drawing them separately, and later trying to deduce their language, rules, and chronological sequence. Various authors (Parker, 1836; Rickman, 1819) patiently compiled the formal catalogs of building elements.

But all this material, which could be used for describing the transformation and geographical distribution of architectural forms at best, was not enough to explain the reason for the architectural evolution. Researchers were beginning to see that it could be strongly conditioned by constructive

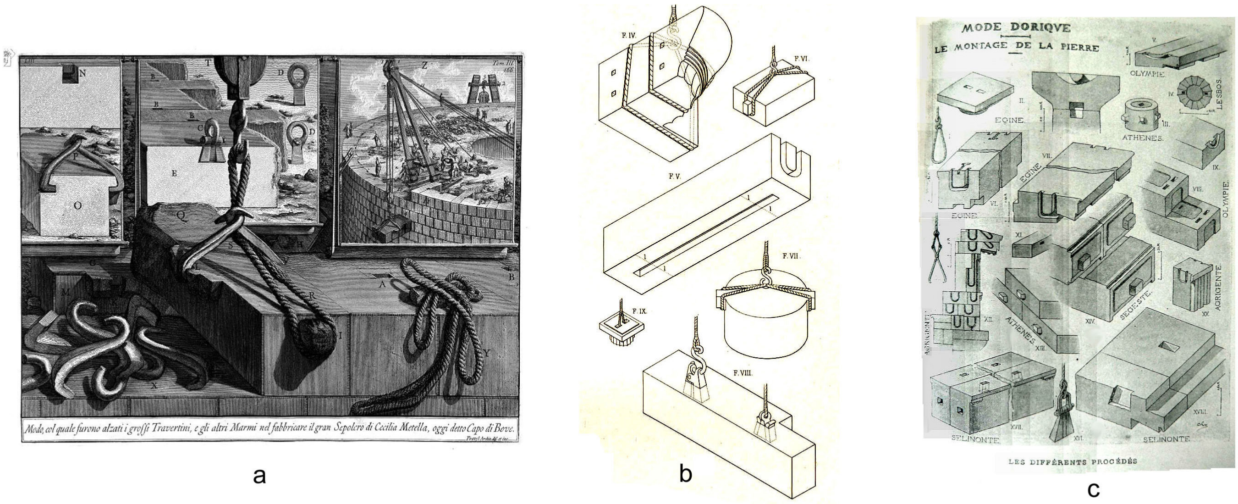


Figure 5. Representation of Greek temple lifting operations, based on interpretations of Vitruvius' ancient machinery. Left, a — Cecilia Metella's tomb under construction according to Piranesi (1756–1757); b — center: lifting devices used in the Selinunte temple (Hittorff and Zanth, 1870); c — a collection of ashlar pieces, adapted to be handled by different tools (Perrot and Chipiez, 1898)

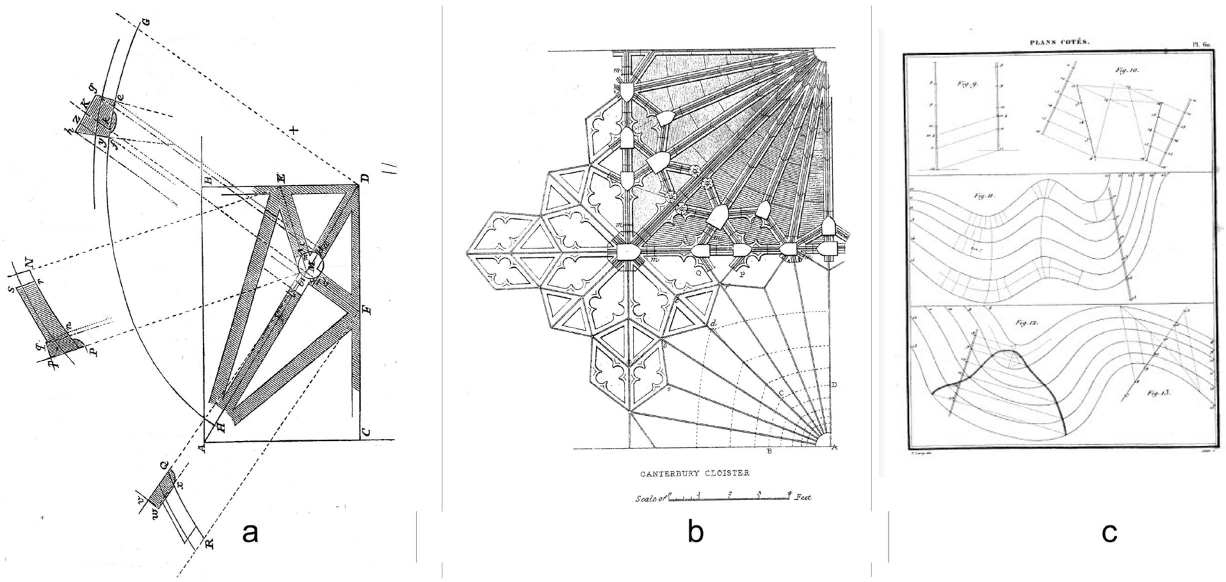


Figure 6. Use of advanced drawing techniques by R. Willis (1842) to study Medieval vaults: a — separate elements defined through the descriptive geometry procedures; b — the surface of the intrados depicted by contour lines. Such techniques may be found in French treatises, such as c — Ch.-F.-A. Leroy (1834), and occur rarely in English cartography

issues, unlike what we can observe in Greek architecture. The study of constructive issues would soon become crucial for certain historians. In this context, elements such as the vault and its supports emerged as a priority research topic. Their types and forms had to be described (Whewell, 1830). But above all, it was necessary to understand how they had been constructed.

Robert Willis pioneered in this field with fundamental work. The problem was not easy to solve. He could not count on enough Gothic ruined buildings (unlike with Greek architecture) to reassemble their vaults from the ruin pieces. Just like Piranesi during his attempts to understand Roman construction, he had to reveal the invisible.

And like Piranesi, Willis understood that the solution could only come to him if he drew the buildings. What Willis wouldn't do is rely on unprovable hypotheses. He realized that what was needed was the most accurate virtual anatomy of the vault. To do this, he would have to resort to a whole arsenal of graphic procedures, some of them recently developed (Giron Sierra, 2016).

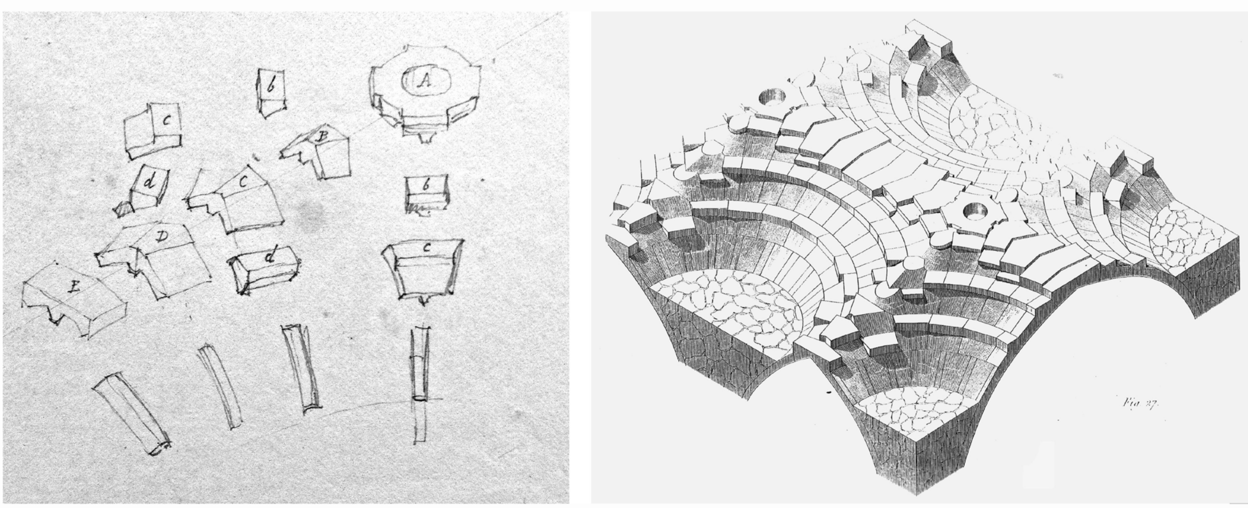
Willis realized that it was necessary to start with a rigorous survey of the two faces of the vault (its intrados and its extrados) and then, from these two surfaces, delve into the inner structure. To deduce and determine each piece's shape, he borrowed graphic procedures from descriptive geometry (a modern science of French origin). He also used contour lines — a technique that was just making its tentative first steps in English cartography — to describe the surface's curvatures (Fig. 6). Finally, he decided that the vaults' extrados needed to be shown in mensurable three-dimensional drawings (Fig. 7). To do this, he used a system of representation that W. Farish had recently invented: isometry (Farish, 1822). Thanks to those drawings, Willis obtained and communicated a better understanding of the relationship between the apparent form and the actual construction of an English Gothic vault.

Visual Models of Perception. Viollet-le-Duc and the Anatomy of Gothic Construction

In France, Viollet-le-Duc approached similar issues with unique ingenuity. If Willis' graphic ability to guess what was within a vault simply through drawing was truly striking, Viollet-le-Duc deserves as much admiration for his capacity to create memorable «graphic models». His anatomical drawings, once contemplated, create a lasting impression, shaping and refining our perception of a building's constructed reality.

To achieve this, Viollet-le-Duc progressively deployed novel anatomical strategies. For example, at first, Viollet-le-Duc (1847) represented the pieces of the «tas de charge» (springing point of an arch) as if they were scattered over a surface (Fig. 8a). Years later, he adopted another solution: he imagined the elements floating in three-dimensional space, separated but close enough to suggest that they were about to be coupled (Viollet-le-Duc, 1859) (Fig. 8b). This change references some innovations that had been introduced years before to medical anatomy visualization. As pointed out by researchers (Bressani, 1996), this procedure may have been inspired by Jean-Marc Bourgery (1831) (Fig. 8e) whose skull plate improved on previous illustrations such as Monro's (1759) (Fig. 8d).

Viollet-le-Duc likely also found inspiration in the stone-cutting treatises developed in the 18th century in France. Authors such as J.-B. De la Rue (1728), A. Frézier (1737), and M. Simonin (1792) studied the tracing operations to define the shape of the stones that made up the construction of typical



a b

Figure 7. Novel techniques that R. Willis explored when drawing the structure of Gothic vaults: a — separating the elements that make up the vault (unpublished study); b — showing the elements assembled on the reverse side of the vault (Willis, 1842), by using the isometric projection developed by W. Farish (1822)

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elements in contemporary architectural practice, such as niches, vaults, or domes. And they routinely illustrated them with three-dimensional images of each resulting piece (Fig. 9a). But Viollet-le-Duc's drawings went further. They had a different purpose and communicative power. They were capable of revealing the previously invisible construction of Medieval buildings with a single drawing that showed how all the components joined together and fitted in with the rest of the building (Fig. 8c).

The novelty of these drawings (just as Willis' work) made a strong impression on French researchers and led to the drawings' circulation and reproduction in other publications. The fact that the drawings appeared in a publication devoted to stone cutting (Lejeune, 1872), where they were celebrated with great admiration, suggests that they could be seen as an extension of this tradition. And, at the same time, as something that was opening up unexpected analytical possibilities (Fig. 9b).

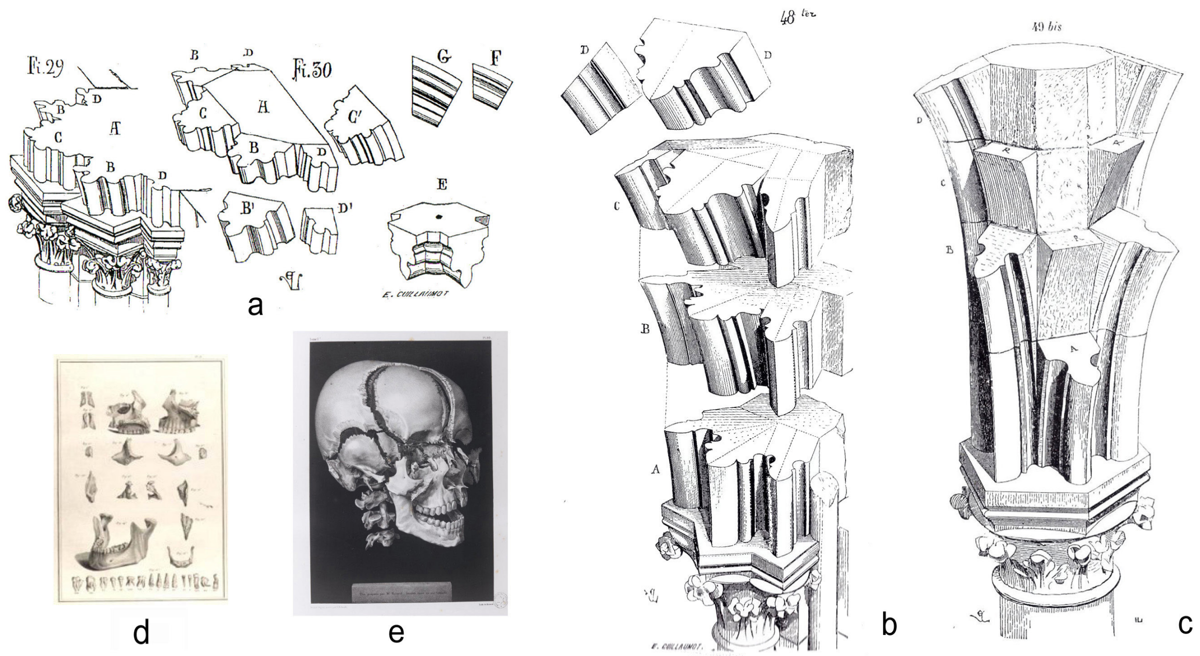


Figure 8. a — the Gothic «tas de charge» of a disassembled vault in (Viollet le-Duc, 1847). Two later versions by Viollet le-Duc (1859) showing: b — each element and its integration with others, and c — integration with the rest of the building's fabric. A similar visual innovation had previously occurred in anatomical science: compare d — A. Monro (1759) with e — J.-M. Bourgery (1831)

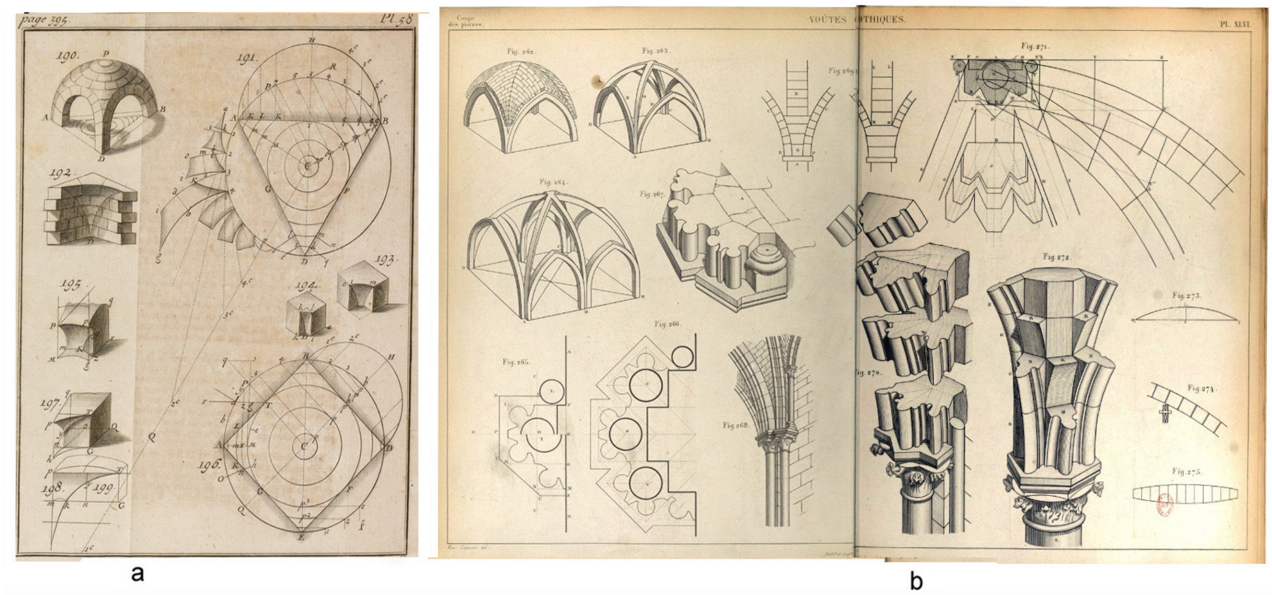


Figure 9. Viollet-le-Duc's anatomies were welcomed as an advanced, innovative new step in the visualization of stone cutting. a — a sample of Frazier's treatise (1737); b — a plate from J.-B. Lejeune's treatise on the topic (1872), with an addition of selected analytical drawings by Viollet-le-Duc

Roman Construction According to Choisy: a Virtual Model for a Clear Vision

In the last third of the 19th century, a fundamental and difficult research issue was still pending: researchers still did not know how Roman vaults had been built. Vitruvius did not describe them, so the only way to solve this enigma was to directly inspect shapeless ruins, composed of an amalgam of concrete and brick that could not be disassembled into pieces. The solution was ultimately found by an engineer, A. Choisy (1873).

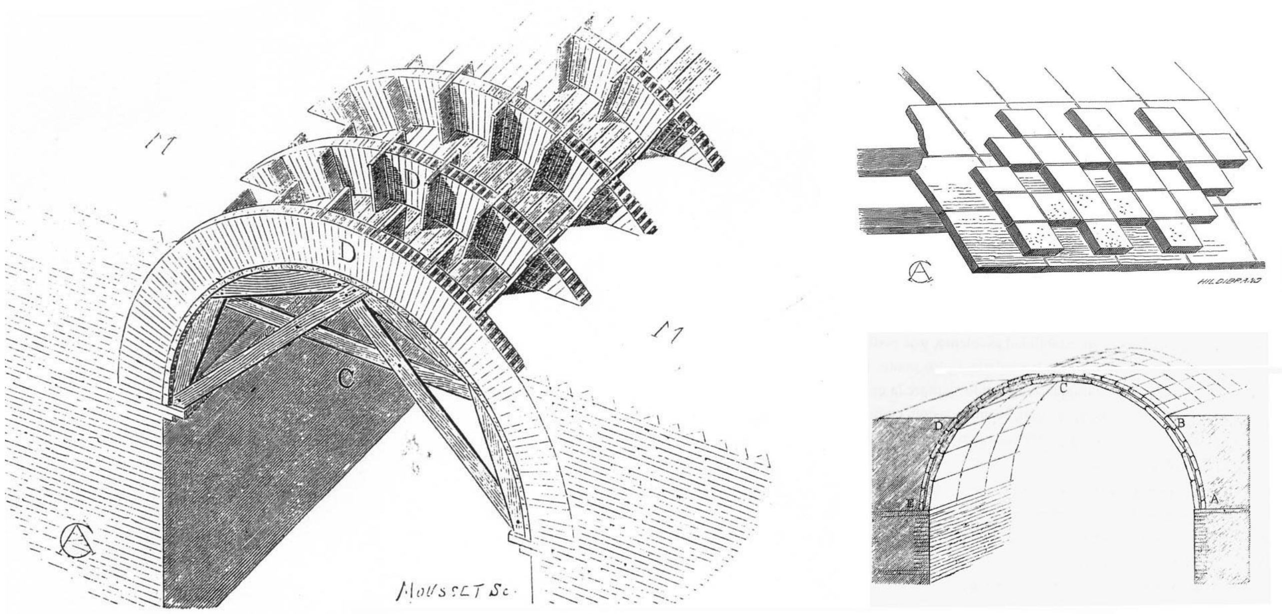
Choisy assured the reader that his work was based on his own notes. But a survey of those ruins, no matter how careful and faithful, could not automatically lead to a solution. The French «pensionnaires» in Rome had already carried out excellent surveys of the ruins' vaults. And yet, the researchers that had wondered about the process of building those vaults had not been able to unravel their secrets (Vaudoyer, 1826–1832).

As Choisy saw, the point was to realize that the analysis of the Roman vault was not an anatomical problem. What was required was a definition of the sequence of operations involved, as well as their functions, in as clear a way as possible. In order to arrive at this definition, he needed a reasonable hypothesis about what could have happened in a Roman building site and a good strategy for visualizing this.

The economic factor was key: the researcher had to examine how Romans had dealt with expensive temporary structures. The assumption that the ancient builders could have used scaffolding and timber falsework, similar to contemporary practices, had caused Piranesi and Viollet-le-Duc to make considerable mistakes in their interpretations of Roman vaults or domes. This mental framework had to be abandoned. Choisy's starting point was the idea that in Rome, timber had been a scarce commodity that the Roman builders had tried to use as little as possible. From that point of view, everything suddenly made sense: it was now easy to understand that the lattice ribs or the brick lining in the concrete had once been the formwork.

With this idea in mind, Choisy was able to «read» the ruins and produce drawings that illustrated their different theoretical construction stages (Fig. 10). Thus, he managed to translate one of the procedures that French engineers used for project commentary to historical construction analysis. He was probably familiar with the impressive chronological illustrations that J.-R. Perronet had published at the end of the 18th century (Perronet, 1782–1789) to explain his bridge projects, a narrative closely related to a great interest in controlling the economy of resources and optimizing time.

It is a paradox that the same engineering background that made him acutely aware of the importance of «technical time» in construction processes seemed to lead him to disregard the importance of «historical time». As it has been pointed out, one of the weaknesses of *L'art de Bâtir Chez les Romains* is precisely the absence of a historical perspective of the buildings' development (Lancaster, 2009).



a b

Figure 10. For Choisy (1873), the Roman vault's construction was not to be treated as an anatomical problem. Describing the sequences of operations and their role was paramount. Sparing timber in the temporary structures would have been crucial. This figure shows: a — lattice ribs, and b — brick lining, as self-supporting formworks

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The next step for Choisy was to demonstrate the results of his research. Choisy would be aware, as Viollet-le-Duc was, that with drawings of sufficient quality, he could create a substitute image of reality: a «cleaned-up» image, capable of modifying our perception in the future. This way, future researchers would see more clearly what had been happening in those ruins and gain more knowledge on the matter.

So it was necessary to choose the criteria both for the system of representation and the narrative strategy. As Choisy himself confessed when he received the medal of honor awarded to him by the RIBA in 1904, Willis' drawings had made a strong impression on him in his youth. This probably explains why he resorted, somewhat surprisingly, to axonometry. While it was, in fact, a system of representation that was particularly well-adapted to scientific and objective knowledge, until that point, it had had very little presence in construction studies. Choisy would handle it flexibly, adopting trihedrons where the angles formed between the measurement axes could vary at will. He chose not to adhere to the English isometrics, or to the more usual continental, «cavalière» perspective.

As for the narrative strategy, he sought one that would help him to see the vault and the successive stages of its construction at a glance. To do this, Choisy resorted to a traditional solution with a very long history; it allowed him to synthesize the whole process in a single image: the layered drawing (see, for example, G.A. Rusconi, 1590; or B.F. Bélidor, 1750) (Fig. 11).

Choisy's plates finally offer a sharp and distinct view of both the elements amalgamated in the vault's mass and its construction stages. Choisy, aware that what he shows is an idealization, adds some arboreal elements to the drawing, to remind us that what we see now lies in ruins.

This image is fascinating in its ambiguity since it allows us to «finally see clearly» what is happening amid the confusion of ruins, while also warning us that what we are contemplating is almost literally a figment of our imagination. All the same, those images made a great impression on other scholars.

Some of them, as J. Durm, did not fully agree with the «neatness» of the drawings and decided to «improve» them by making more down-to-earth (and clumsier) versions (Hassler and Pliego, 2009). The

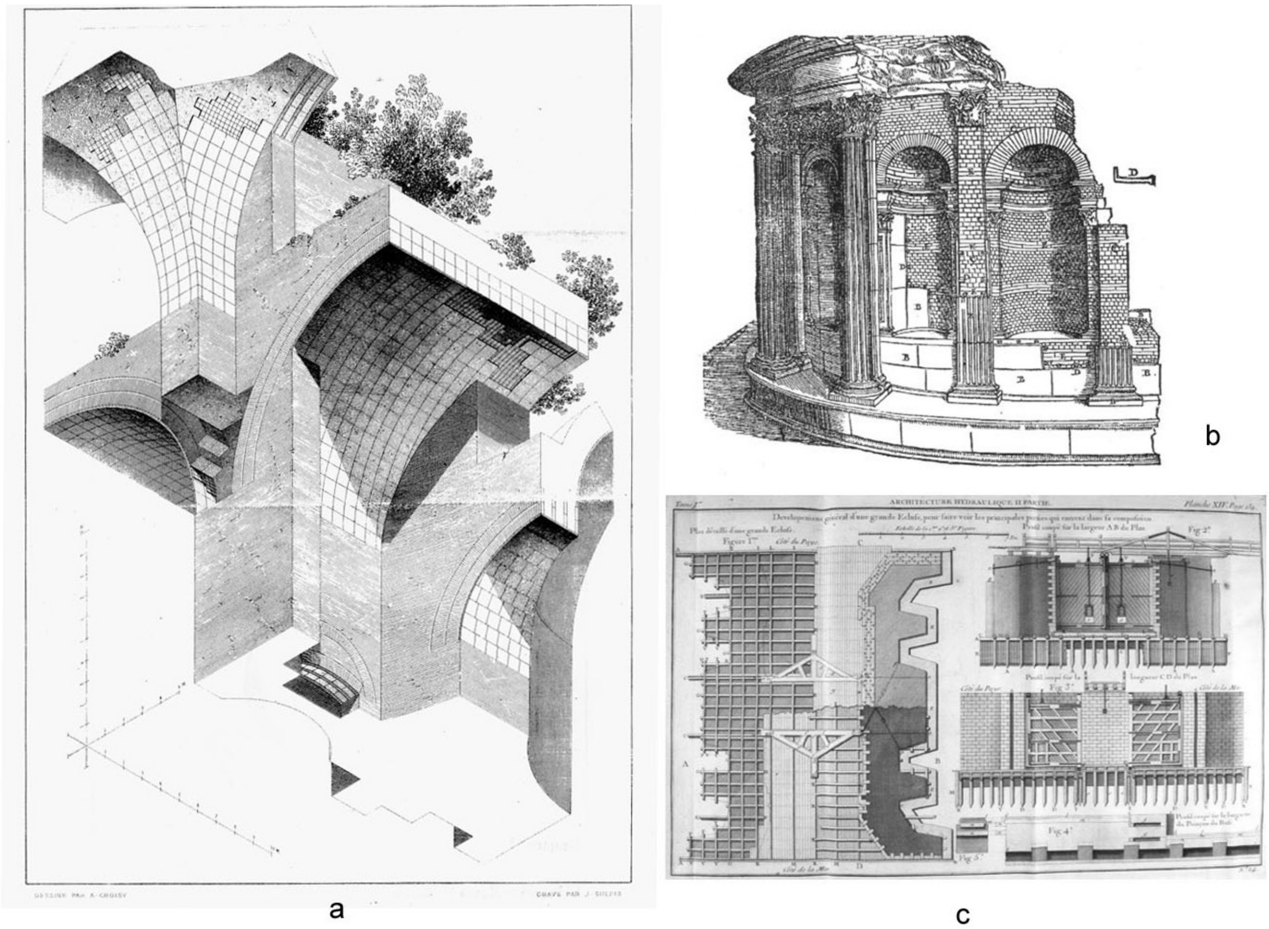

Figure 11. a — to conclude his research, Choisy (1873) created drawings allowing for an «at a glance» reading of a Roman vault and its successive construction stages. He relied on a time-tested narrative device, easy to find in Vitruvius' editions, b — (Rusconi, 1590); or engineering treatises, c — (Bélidor, 1750)

spread and diversification of those images deserve further research (Fig. 12).

Lost Timber Construction Systems. Choisy's Graphical Method for «Reading» Them in Stone Buildings

So far, we have seen how drawing helped interpret the hidden parts of a stone building or recreate a specific ruin. But the history of construction has another branch, which was still mostly unexplored in the last third of the 19th century: ancient timber construction. That was a difficult subject since by their very nature, the timber structures were very perishable and had largely disappeared. Could drawing help researchers find out what they had looked like and virtually restore them?

Since the middle of the century, various explorations had revealed that the stone tombs and monuments of different ancient peoples and civilizations could often be interpreted as the petrification of a previous timber structure (Fellows, 1839) (Fig. 13a). It became increasingly clear that this metamorphosis was a relatively common phenomenon: buildings constructed in stone in Etruria, Asia Minor, Persia, or India, among other regions of the world, preserved a fossilized carcass of another structural system (Viollet-le-Duc, 1863) (Fig. 13b). Based on a sum of these contributions, Choisy, in his *Histoire de l'Architecture* (1899), introduced a procedure for «recovering» many lost timber structural systems (Giron Sierra, 2009) (Fig. 13c).

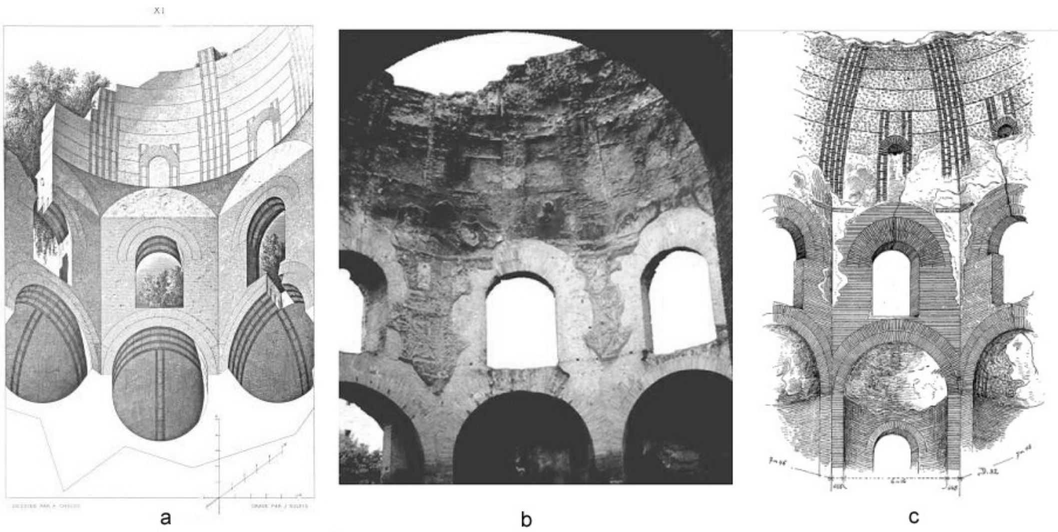

Figure 12. Choisy's drawings as an idealized visual model and their alterations. Compare: a — the Temple of Minerva Medica (Choisy, 1873) with b — a photograph of its real state. Those images had a significant impact; c — some scholars (Durm, 1885) even «improved» them to make them closer to reality, which stripped the drawings of their communicative power

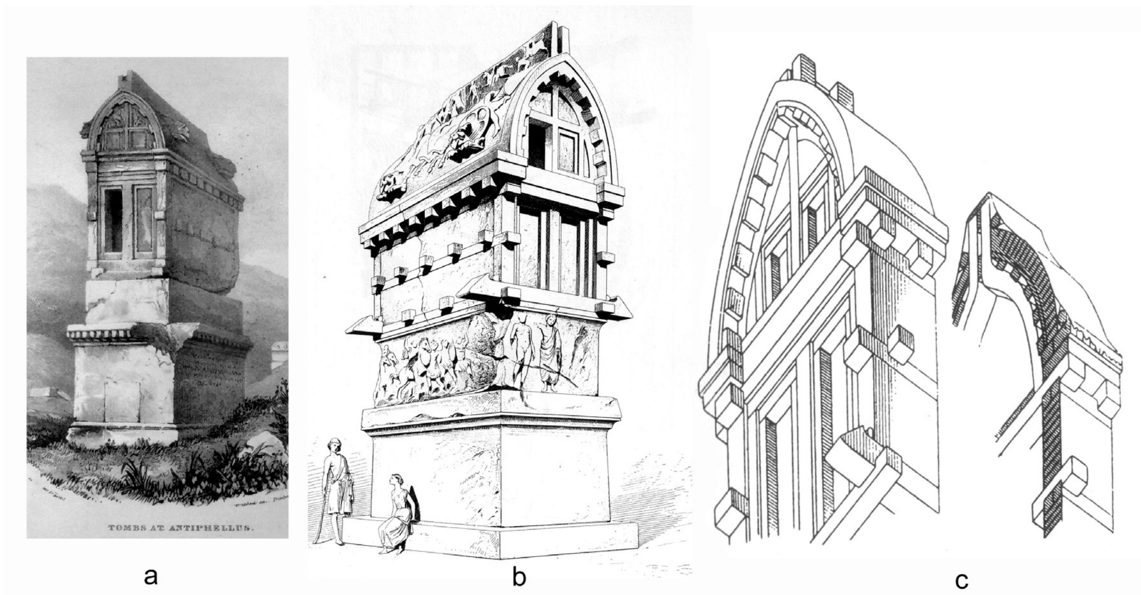

Figure 13. Depictions of antique petrified timber structures, as recognized by scholars. a — Lycia Sarcophagus (Fellows, 1839); b — (Viollet-le-Duc, 1863); c — Choisy's drawings (1899)

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From the photos and illustrations by other authors, Choisy made deductions about the pieces of the primitive timber structures, which had supposedly been «petrified» in those monuments, and how they had been assembled. This way, he revealed something invisible, in this case not because it was hidden inside the construction, but because it had undergone a metamorphosis and had been replicated in stone. These sketches present a hypothesis that we can eventually compare with other well-documented procedures of making timber structures (Figs. 14a, b).

Crossing and Comparing Construction Systems: The Parallels

Various studies that began to appear in the middle of the 18th century aimed to discover the laws or patterns that could have governed the evolution of the past's different architectural styles (Leroy). Many scholars throughout the 19th century joined this research. As shown by Durand's impressive pioneering contribution (1799), the scholars relied on a graphic tool, the «parallel»: a panel of buildings drawn to the same scale. Parallels were particularly useful for an in-depth approach to a vital point: the influence of real dimensions on each type of architecture and its evolution over time.

Parallels may unveil the structural design rules used in the past and how they were affected by scale change. For example, they made it possible to investigate whether the geometrical principles for dimensioning the domes were independent of their size (Patte, 1770). Or to deduce empirically, based on sufficient case studies, a formula for designing a particular element (for example, a formula for determining the stability of a wall, as in Rondelet, 1802–1810). It was also possible to examine the changes that a single building element underwent as it grew in size and to determine its ultimate dimensional limits, as was the case, for example, with the Rondelet roof truss studies in 1802–1810 (Giron Sierra, 2015).

Parallels were also used to measure the relative «efficiency» of building systems from the past. For example, scholars relied on parallels to determine whether Gothic architecture was «superior» to Renaissance architecture, efficiency-wise. One way to compare their performance was to evaluate how much it «cost» — in terms of investing in a certain mass of structural material — to cover a space (Durand, 1799–1800) (Fig. 15a). With plans drawn to the same scale, it was easy to examine each system and determine how much space was taken up by the walls of the buildings and other structural elements and how much free space was left (Rondelet, 1802–1810) (Fig. 15b). By arranging items in chronological order, researchers were also to infer from parallels whether a style «progressed», that is, whether its performance was optimized over time.

Those comparative drawings may also show how growing in size affects an element's design (Reynaud, 1850) (Fig. 16a). Or highlight the difference between the scale limits that each building system could reach. For example, (Durm, 1885) demonstrates this by «inserting» sections of Gothic temples into the vaults of the Maxentius Basilica in Rome (Fig. 16b)

Discussion

This article has outlined a way to answer the questions regarding the extent of drawing's contribution to solving the problem of «seeing the invisible», which the pioneers of the history of construction asked themselves during the 17th to 19th century.

To do this, we have followed a method that has allowed us to make a first provisional overview, based on a selection of monographs. We have observed, as far as possible, the chronological account, highlighting some pioneers in the history of construction, identifying the problems that they

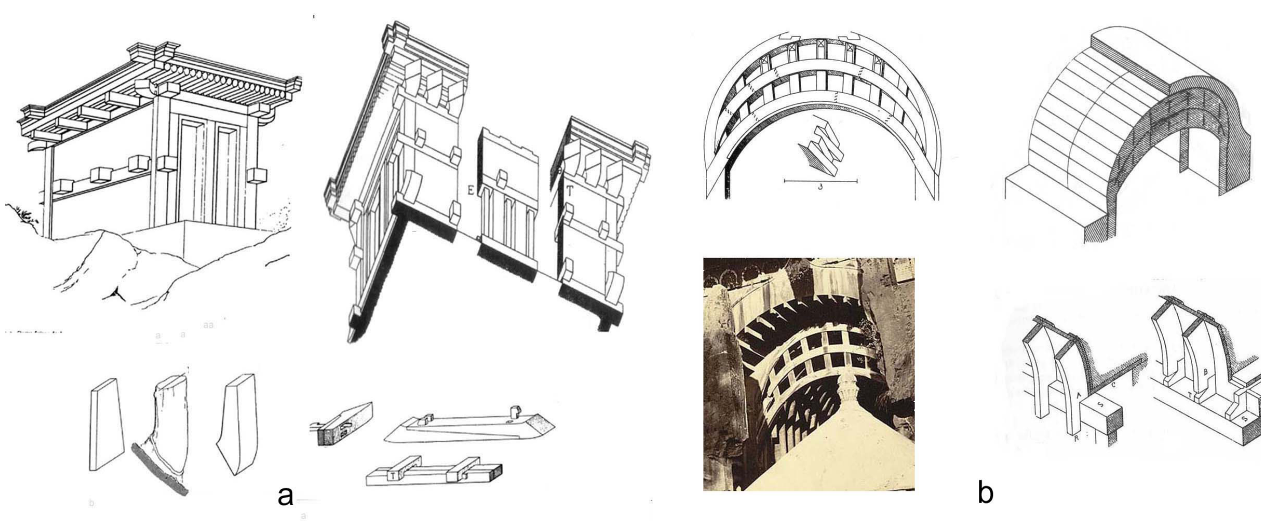


Figure 14. a — Lycia monuments (Benndorf, 1884); b — a photo of Indian cave architecture (Le Bon, 1887). To the right of each image, note Choisy's (1899) hypothesis visualizing the respective primitive timber structure systems

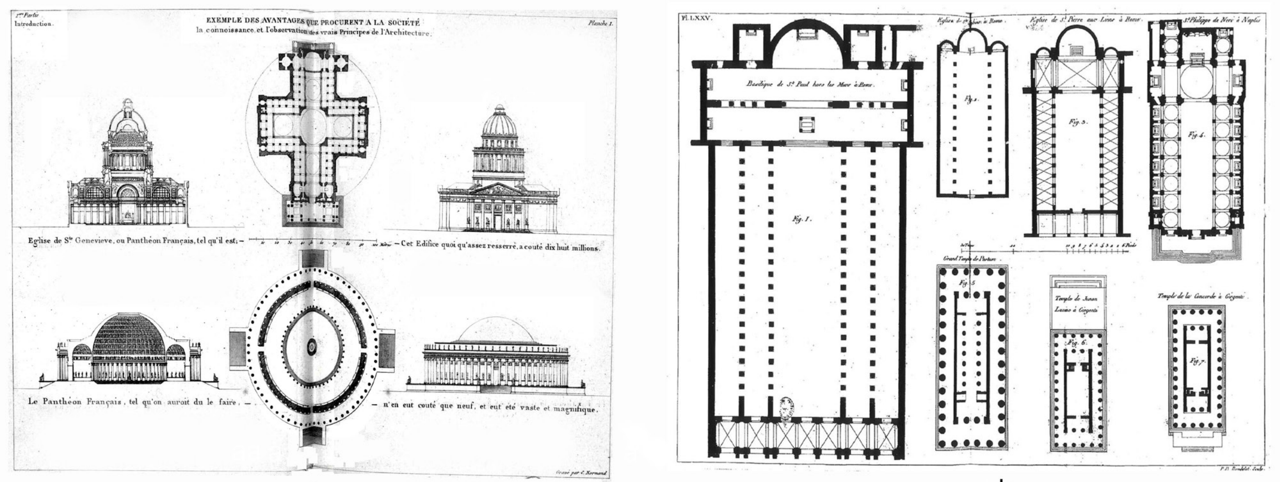
faced and the methods that they used for addressing these problems, and studying the role of drawing in each case (i.e. whether drawings were used for analyzing, showing, or comparing).

This synopsis shows the general picture. Due to space limitations, the study of the materials we have presented cannot be exhaustive. It is based on a limited number of very relevant authors. We have identified many other authors that should be included in a more comprehensive and detailed study (such as Canina, Chipiez, Curtius, Dieulafoy, Gauthier, Parker, Patte, or Perrot), but have deliberately set them aside. In order to have a complete picture, it will also be necessary in the future to identify and research more sources (probably «hidden» in chapters or sections of works on architecture) and to extend the geographical scope of this search, which is limited in this study to Western Europe.

Likewise, the possible impact of some innovations on the scientific drawings produced during that period remains to be studied. As for the images that were important as the «mental frame», there are some studies about their dissemination (Gil and Giron Sierra, 2009; Hassler and Pliego, 2009). But much remains to be done if we are to have the full picture, including the image distribution maps and the studies of their versions, impact on other authors, and their relationship with other texts (conflicting, independent or not).

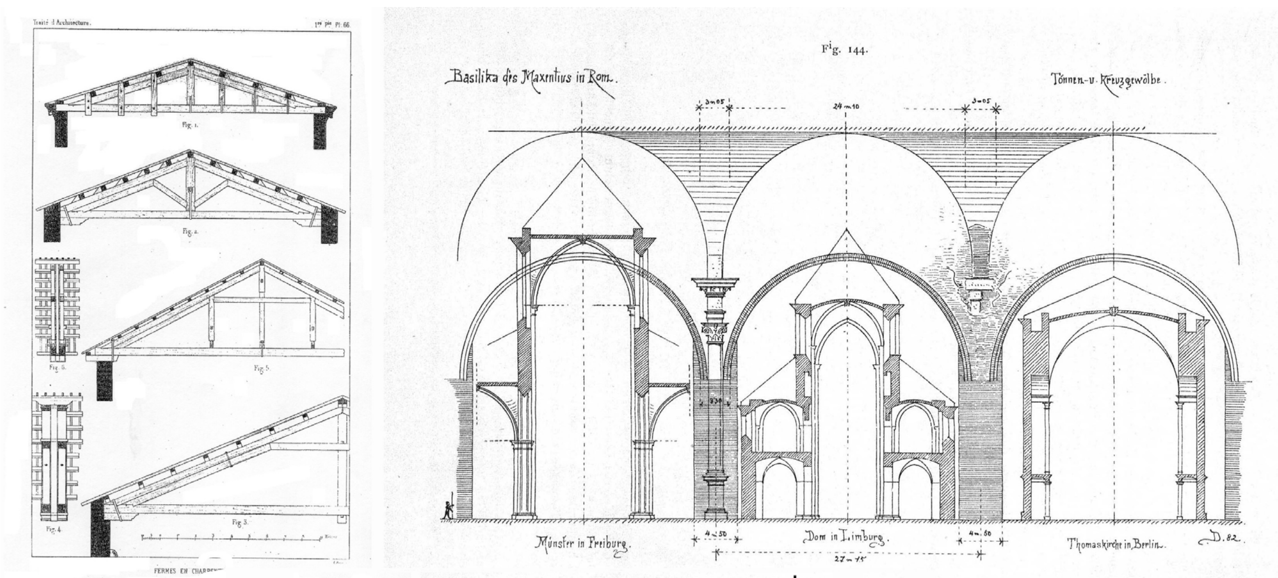
Conclusion

The provisional conclusion that we have reached in this study is that drawing emerged as a



a b

Figure 15. The parallel as a tool for investigating the effectiveness of different construction systems and comparing the mass taken up by the structure with the free space: a — Durand, 1809; b — Rondelet, 1802–1810



a b

Figure 16. The parallel as a tool for determining the scale limits for different elements and construction systems: a — roof trusses in (Reynaud, 1850); b — a comparison of spaces covered by Gothic and Roman constructions (Durm, 1885)

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fundamental non-verbal way of thinking among the pioneers of the history of construction in the 18th and 19th century.

It allowed them to analyze, assemble, and virtually dismantle a structure or extract dimensioning rules based on operational drawings (the scientific and technical drawing type developed in the 19th century); these insights could be circulated and transmitted using drawings that acted as «mental frames».

We have pointed out how drawing was used for exploring plausible graphic hypotheses about the hidden aspects of Roman construction, while combining «in situ» observation with materials borrowed from indirect sources, such as the drawings in Vitruvius' edition (Piranesi, 1756), or for imagining the lost timber structure systems in buildings that would exhibit their petrified versions (Choisy, 1899). We have seen how the scientific and technical drawing (descriptive geometry) procedures that appeared throughout the 19th century allowed scholars to deduce the processes of transport and placement of the pieces making up the Greek temple from dispersed fragments (Cockerell et al., 1830, Hittorf and Zanth, 1870; Penrose, 1851) or to apply a rigorous anatomic structure to the «non-destructive analysis» of the Medieval vaults (Willis, 1842). We have also observed how other novel scientific drawing procedures, such as parallels on the same scale, were used in the 18th–19th century for studying, through comparisons, how size and scale affected the rules for designing various structural systems and for analyzing system efficiency (Durm, 1885; Rondelet, 1802–1810).

On the other hand, we have pointed out how in some cases, drawing became a «substitute» for reality, capable of orienting and clarifying the perception of entities that are difficult to discern in the observable construction. We have found the «mental frame» effect in Viollet-le Duc's anatomical drawings, which made the viewer «see» the different parts of the «tas de charge» of a Medieval vault separately and just before being assembled at the same time, as well as in Choisy's 1873 work that clarified the different layers that compose the construction of the Roman vaults, or in another work of Choisy (1899), which brought the original timber structure, lost within the stone, into the spotlight.

These drawings, which were the result of careful research into reality using the construction anatomy visualization techniques already established in the 17th–18th centuries (Rusconi, Belidor, Perronet, among others), became the non-verbal expression of analytical thought. This, with different degrees of autonomy and independence from the text, would later circulate among other construction historians.

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