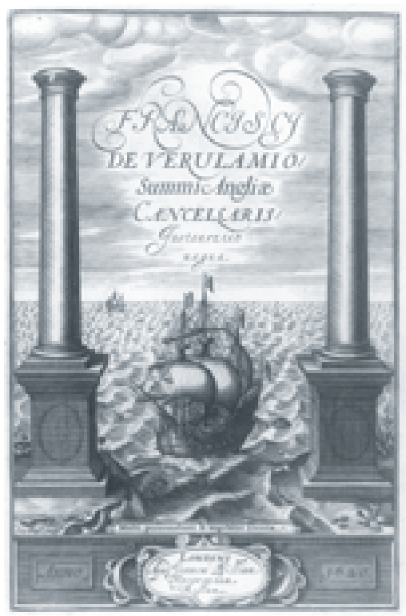
Secrets of the Master Builders

Today, a builder tasked with erecting a dome need only refer to the appropriate engineering literature to confirm the structural design and check the load-bearing strengths of the materials required. By contrast, many of the daring domes and cupolas that adorn the churches of Italy are the product of experience gained through craftsmanship and passed on in oral traditions from one master builder to the next. This unwritten system of knowledge is being researched by **Elisabeth Kieven,** *Director at the Bibliotheca Hertziana in Rome, and her colleague* **Hermann Schlimme,** *in cooperation with the* **Max Planck Institute for the History of Science** *in Berlin.*

Until well into modern times, the art of construction was based on the practical skills passed on in oral traditions from one generation of craftsmen, master builders and architects to the next. It wasn't until the end of the 18th century that this knowledge began to be scientifically codified. The monumental structures of classical antiquity, the cathedrals of the Middle Ages and the audacious domes of the Renaissance were all created without recourse to institutionally trained engineers.

The *"History of Architectural Knowledge"* project focuses on precisely these pre-scientific eras, as well as on the transition to the modern scientific approach. "We are interested in the practical knowledge of the builders in areas ranging from civil engineering to construction site organization," says Hermann Schlimme, "as well as in reconstructing their methods of design and graphic representation." So great were the logistical and technical skills of the early master builders that the underlying methods and processes can under no circumstances be described as basic common knowledge. On the contrary, they constitute an implicit, unwritten system of knowledge that is now being investigated by researchers at the two Max Planck Institutes on the basis of individual case studies drawn from many eras.



Title page of Francis Bacon's Instauratio Magna, which appeared in London in 1620.

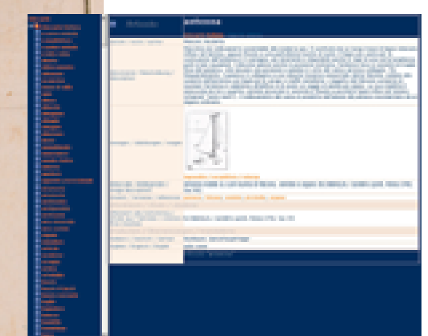
Photo: Bibliotheca Hertziana

Traditional architectural history considers the process by which buildings progress from design to implementation, focusing on aesthetics, form and representation, historical categorization and the development of ideas. The project in which the Max Planck scientists are now engaged, however, takes a new approach. Research into our cultural history has thus far paid little heed to the fund of architectural knowledge possessed by the builders of old and the manner in which this knowledge developed and interacted with other disciplines.

Given that practical knowledge was passed on verbally or diagrammatically, a study of potential sources would appear to be a difficult task, at least at first sight. Learned architectural discourses were common in early modern times. However, treatises of this kind were intended primarily to demonstrate the importance of architecture by reference to antiquity, without further consideration of technology or methods. Often, the knowledge that passed from one skilled builder to another was never committed to paper. Despite this, there are ample sources, written or graphic, awaiting analysis at the Bibliotheca Hertziana – it is simply a question of applying

Photo: Istituto Nazionale per la Grafica, Rome

Luigi Vanvitelli: Investigation of the structural condition of the dome of St. Peter's, 1743.



Glossary of historical construction in Italy.

Photo: Bibliotheca Hertziana

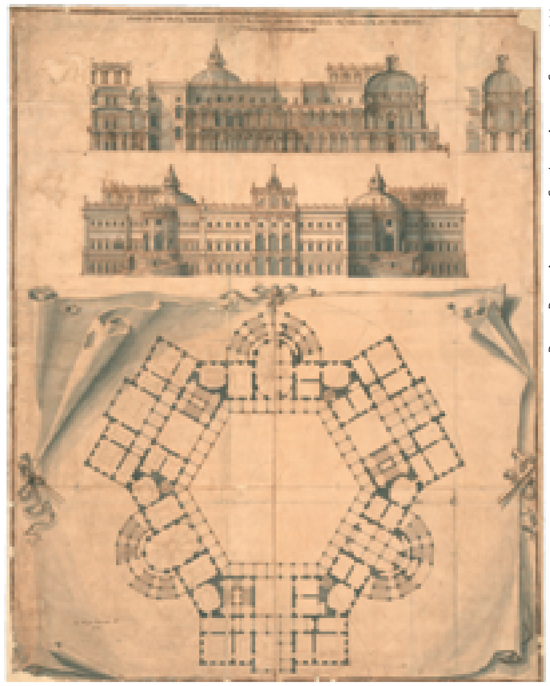


Photo: Rome, Academia di San Luca, Archivio Storico, 141.

A palace for three royal personages of equal rank: This design earned Filippo Juvarra first prize in the "Concorso Clementino" in 1705.

a different analytical approach to that previously adopted in architectural history.

"Our work is based on graphic, written and structural sources – in other words, on drawings, specifications, or indeed, the buildings themselves," says Hermann Schlimme. The profiles the Institute has compiled from this source material are not restricted to individual buildings, but instead focus on individual areas of knowledge, such as designs, accounts and record keeping, or the technical aspects of vaulting. Thus, for example, records of construction costs can themselves become a subject of research.

One result of this approach earned international renown: an online glossary of historical Italian construction terminology. In Schlimme's view, by systematically listing the specialist terms used in early construction records – terms that were often colloquial in origin and are nowhere to be found in historical dictionaries – and making these freely available on the Internet, the Institute is "filling a gap in the history of architecture." Invitations to present the "Glossario" project at international conferences such as that taking place in Ravenna in October 2005, and an appointment to the Scientific Committee for the Second International Congress on Construction History 2006 in Cambridge confirm the growing interest in the Hertziana researchers' approach to the systematic study of the traditions of practical knowledge.

Schlimme sees the increasing attention as part of a wider evolution in the attraction of construction history, and believes that the project can even share in determining how the subject develops. Such diverse publications as the Frankfurter Allgemeine Zeitung and the Newsletter of the Construction History Society reported in great detail on the *Building and Knowledge* conference organized by the Bibliotheca Hertziana in autumn 2003.

The joint project shared between Rome and Berlin goes beyond the traditional scope of architectural history. It integrates not just the sacred and the splendid, but also buildings of functional import, such as fortresses, dams and canals, as well as common dwellings. In this way, it enriches and stretches the bounds of research, similar to the quotidian historical approaches used in the science of history. Thanks to the project, even the numerous architectural drawings that have existed since the 16th century are now being studied in a new light.

Drawings Offer Great Insights

Sketches originally drawn to illustrate design suggestions, document the progress of construction or clarify particular work stages conceal valuable but previously neglected clues to the contemporary understanding of building practice. Provided, of course, that one knows where to look. Design and construction drawings do more than just depict the genesis of the structure in question: they are also a major source of information for researchers. They provide first-hand experience in the development of drawing and illustration techniques, and show how information was codified, dimensions indicated and methods of construction represented.

It was an appreciation of this new perspective on architectural drawing that led Elisabeth Kieven, who has studied the history of this medium for many years and specializes in researching the architecture of the 17th and 18th centuries, to initiate the LINEAMENTA project. Under Kieven's guidance, an online research database of architectural drawings is being created. The database contains scans of the original documents in the highest resolution currently achievable, allowing even the structure of the paper and the piercings left by compasses and dividers to be seen on screen. LINEAMENTA brings together drawings that are scattered throughout the world, allowing researchers to access them in virtual form and gain new insights into this source material.

According to Elisabeth Kieven, the database allows, for the first time, comparative studies of documents whose originals are stored thousands of miles apart, shielded from the light of day and kept under lock and key in archives and collections. The development of practical traditions and construction techniques, the relations between clients and architects, master builders and craftsmen, and the exchange of ideas between artists can all be researched with ease via a desktop monitor. "This newly acquired overview of the material is bound to raise many new questions," says Kieven.

What fascinates Hermann Schlimme most about the joint project is the interaction between construction and other fields of knowledge at the dawn of the modern age. A case study of Florentine construction accounts records from the 15th century undertaken jointly with Jens Niebaum has revealed that the Italian banking system that developed in the late Middle Ages substantially influenced construction billing methods. One particular account ledger kept by an employee of the Medici bank for the Church of San Lorenzo proved to be an ideal "exemplar of the opportunities for knowledge transfer."

Schlimme, a specialist in architecture, history and art history, and who wrote his doctoral thesis on Roman church facades of the early modern age, is focusing in particular on the interaction between the emergence of modern natural sciences and building construction in early modern times. He describes his field as "largely terra incognita." Elisabeth Kieven explains why this is so: she believes that the subject was "too technical" to be of interest to art historians, whereas the history of science looked no further back than the beginnings of the scientific codification of building techniques and the institution of engineering training in the late 18th and, above all, in the 19th century. Some essential elements of the history of construction were thus left in limbo between the two disciplines.

In this respect, the project is attempting – with success – to build bridges by uniting art and architectural history on the one hand with science history on the other. In Elisabeth Kieven's words, "Architecture has its technical side, but it also embodies artistic aspirations. Architecture unites art and technology in an exemplary manner." Consider the survey of the dome of St. Peter's, prepared by the Roman architect Luigi Vanvitelli in 1744 to document cracks in the structure. The precise draftsmanship with which the architect recorded the damage paved the way for the first known diagnosis of material fatigue in the tie bars by the physicist Giovanni Poleni.

Hermann Schlimme theorizes that, over time, the pioneering findings of the natural sciences – particularly since Galileo Galilei (1564 to 1642) – have consciously and increasingly been implemented in building construction. However, given the source material available, it is worth asking whether a reverse influence also applied. "In the beginning, construction was one of the driving forces behind the development of modern science. Right from the start, modern science has been characterized by a curiosity about common knowledge," says the Max Planck researcher.

Philosophers Discover Construction Technology

It was in the 15th century that philosophers began to concern themselves with crafts and construction skills. Technology and craftsmanship had previously played no part in the education system founded in antiquity and based upon the *septem artes liberales*, the seven liberal arts, which had been obligatory throughout the Middle Ages. Indeed, a concern for such matters was considered unworthy of an educated man. The accepted scholastic view of the world was still dominated by the teachings of Aristotle – a theoretical construct that was at a remove from day to day realities. Post-1400, however, cracks began to appear in the edifice that had for generations appeared inviolable. Nicholas of Cusa discoursed on aspects of construction technology and methods of craftsmanship in his treatise entitled Idiota De Staticis Experimentis (1450). "Thereafter, the line was crossed with ever greater frequency," says Schlimme.

From the late 16th century onward, an experimental approach to understanding nature steadily gained in importance. Summing up this new perspective, the researcher continues, "The knowledge possessed by craftsmen came to be regarded as an alternative to Aristotle. The methods used by the crafts trades, particularly construction skills from scaffolding to vaulting, were looked on as a kind of pool of experiments on the basis of which the laws of nature might be determined."

In an appendix to his extremely influential Instauratio Magna of 1620, the philosopher, statesman and scientist Francis Bacon (1561 to 1626) drew up a schedule of 130 fields of knowledge that he deemed important, most of them involving crafts trades and including a dozen aspects of construction, such as stonemasonry and the manufacture of tiles, mortar and glass. Bacon considered the technology of his age to be highly advanced and wished to use it as a new model for the philosophic process he regarded as antiquated and mired in Aristotelian scholasticism. At the same time, he was critical of the fact that, while builders applied this technology, no

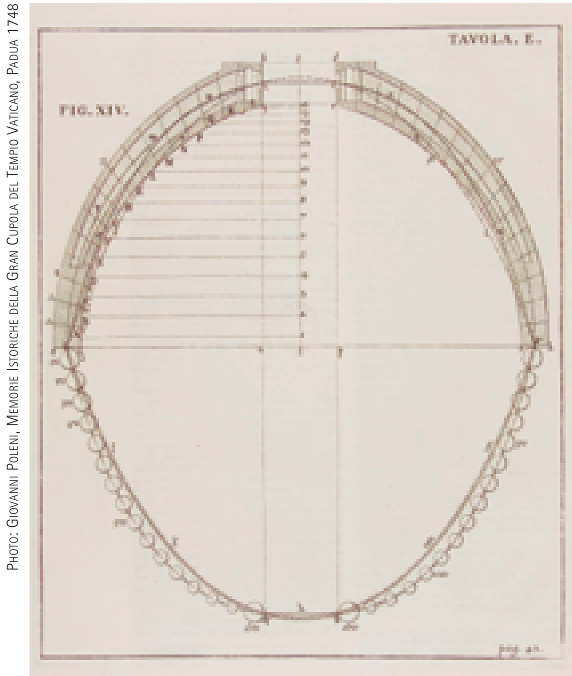


Photo: Giovanni Poleni, Memorie Istoriche della Gran Cupola del Tempio Vaticano, Padua 1748

If one reverses the form adopted by a looping chain, the result represents the perfect pressure line – the ideal pattern for a vault. So wrote Robert Hooke in 1675. Giovanni Poleni demonstrated the stability of the dome of St. Peter's by showing how the reversed chain pattern was still to be found in the cross-section of the dome as it was built.

PHOTOS: BIBLIOTECA NAZIONALE CENTRALE DI FIRENZE

Masterly designs: Illustration from the manuscript Fondo Nazionale, II 46

attempts were made to analyze its physical principles.

Schlimme has found examples in Italy of the interaction Bacon assumed existed between construction and the emerging sciences. Recent research has shown that, for example, Galileo Galilei's studies of the material-specific load-bearing limits of various types of timber were prompted by the practical experiences of craftsmen working in the Venetian naval dockyards. "It is not the case that he explains something to the dockyard workers, but rather that their experience forms the basis for his experiments," says Schlimme, summing up the research by the partner institute in Berlin. This parallels his own thesis that the natural sciences are the product of an interest in everyday systems and technology, particularly in the field of construction.

Consider, for example, a treatise by Galileo's successor as mathematician to the Grand Duke of Tuscany, Evangelista Torricelli (1608 to 1647). He analyzed the static and dynamic principles inherent in the typically used but never investigated technique by which Florentine builders repaired longitudinally cracked columns by ringing them with narrow iron bands. Hermann Schlimme believes that several aspects of a scientific approach are clearly identifiable from this episode: Torricelli analyzed and quantified a technique that obviously worked well and had no need of further investigation – and he was focusing on workmanship that fell outside the scope of the *artes liberales*. "If you think this through, what it means is that knowledge should be interchangeable. It puts a question mark over the narrow rules of the guilds that often shrouded their skills in secrecy."

ARCHITECTURE IS FOUNDED ON PHYSICS

Torricelli's studies, inspired by the practical knowledge of contemporary building workers, are an example of the emergence of a soberly mechanistic view of life – in contrast to the more organic Renaissance view that was oriented strictly toward the standards and anthropomorphic conceptions of antiquity.

The interaction between construction and the emerging sciences reached a new level with the arrival of scientifically oriented academic institutions in the 17th century. Neither the universities that long remained anchored in scholasticism and where construction as such had no role to play, nor the craft guilds that guarded their knowledge against dissemination were suited to promoting the development of a scientific approach. Likewise, the great arts academies founded in Italy near the end of the 16th century were mainly dominated by painters, and architecture initially played an entirely subordinate role.

During the course of the 17th century, relatively small, open discussion groups were formed on the pattern of the 15th century academies that were devoted to a study of antiquity. Often, these groups were supported by local nobles and comprised members of varying educational backgrounds. Schlimme is making a detailed case study of a previously unheeded manuscript in the National Library in Florence – one that describes the activities of the long forgotten Accademia del Sig. Abate Ottavio della Vachia, or Accademia della Vachia, for short. This private academy, or group, was active in Florence around 1661/62. Of the thirteen named members, seven were outstanding scientific figures in the Grand Duchy of Tuscany. They regularly met on Sundays to engage in open discussion and apply a scientific approach to any number of topics, including construction.

Of particular interest is the architect and mathematician Cosimo Noferi, who was born around 1635 and died shortly after 1663. Noferi was strongly influenced by Galileo and was familiar with all the experiments and studies associated with the latter, but in all probability was himself largely unknown during his lifetime. In retrospect, however, he may be regarded as one of the first architects to attempt to establish the approach advocated by Bacon and Galileo in the field of construction. In his four-volume manuscript series TRAVAGLIATA ARCHITETTURA, which was likely intended for publication, he proclaimed his intent not only to name the construction techniques in common use, but to explore their backgrounds in physics. Architects, according to Noferi, should work in the manner of scientists, and not as philologists fixated on antiquity.

The questions discussed by the Academia in the field of construction included the design of roof structures and roof frames and bridges with an arch span of 60 meters. They also touched on structural alterations to existing palazzos, roofing domes and cupolas, and a machine for driving piles. While it was common practice to determine the size of the water pipes required for fountains and waterworks by trial and error, the academicians rejected this procedure and tried instead to calculate the necessary diameter in advance, bringing scientific knowledge and methods to bear.

When the intention was announced to raise the roof height of the Jesuit church of San Giovannino in Florence, the academicians set themselves a task that concerned the concrete modifications of a building: they determined to develop a space-saving roof frame that could subsequently be installed in a timber barrel vault projecting into the roof void. The usual roof trusses with horizontal main (foundation) beams would be dispensed with. A dozen or more solutions proposed by the Vachia members have been preserved, including sketches, physical principles and commentaries.

In his TRAVAGLIATA ARCHITETTURA, Cosimo Noferi speaks of the "public discussion among all interested parties" regarding the optimum solution, and in a kind of research report, he also describes the alternatives that were not used. In the spirit of the "republic of scientists" demanded by Bacon, new knowledge was immediately made public and was not reserved to members of a specific guild.

A "PRIESTLY" ENGINEER

The truss design that was ultimately constructed was the brainchild, not of a master builder, but of a priest named Domenico Fontani, a member of the Accademia della Vachia. The structure built to his plans remains to this day in its original position in the roof of the church. Fontani's – for Italy – highly unconventional solution appears to Hermann Schlimme's eyes to be a "stroke of genius." It is "almost as if geometric figures had been reproduced in a structural design." In point of fact, Fontani distinguished himself in the academy as an authority on geometry. Another unusual feature was the lack of the otherwise elaborated crafted joinery, described by Schlimme as a "foretaste of structural engineering design."

The fact that the truss was prefabricated before being lifted onto the church roof, thus streamlining the construction site, offers further proof of a significant change of pattern. Schlimme concludes that the Accademia della Vachia successfully implemented the demands of Galilei and Bacon, namely for the systematic and experiment-based expansion of knowledge. As Bacon had wished and so impressively depicted on the title page of his INSTAURATIO MAGNA, they broke through the barriers of the ancient world and its attendant knowledge as symbolized by the Pillars of Hercules.

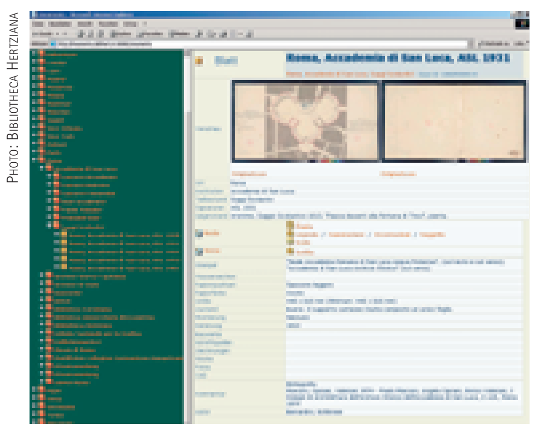
The interchange between building construction and the natural sciences ended with the closing of the 17th century, when structural analysis and materials science became core elements of the scientific approach taught at the Académie d'Architecture and later at the École des Ponts et Chaussées in Paris. With the foundation of polytechnic schools toward the end of the 18th century, the scientific approach in turn became part of an engineer's training that became separate from that of an architect. "The interaction between construction and science that began with the interest taken by philosophers in technology finally became institutionalized. What began as a discussion became a discipline in its own right," Hermann Schlimme explains.

The "History of Architectural Knowledge" project is not simply a reconstruction of an interdisciplinary history: it offers proof of a once commonplace, intensive interplay between disciplines. Nevertheless, the project could add wings to the current debate surrounding interdisciplinarity. In Schlimme's view, Nicholas of Cusa's courageous act in breaking with the rigid system of the seven liberal arts and the unfettered discussions at the early academies should serve as a model for the present: "This openness and the capacity to forge links is something we need now at universities. Not as a luxury option, but as the nucleus of a knowledge-based society."

ANNE GOEBEL

The online glossary of historical Italian construction terminology is available at www.biblhertz.it/forschung

PHOTO: BIBLIOTHECA HERTZIANA



LINEAMENTA research database of architectural drawings.