Nuts & Bolts of Culture, Technology and Society

Construction History Vol. 3
Edited by: Robert Carvais, André Guillerme, Valérie Nègre, Joël Sakarovitch
Masonry Constructions as Built Archives: An Innovative Analytical Approach to Reconstructing the Evolution of Imperial Opus Testaceum Brickwork in Rome

Gerold Eßer
Vienna University of Technology, Austria

The Colosseum, Trajan’s Market, the Baths of Caracalla and the Basilica of Maxentius: the monumental ruins of the imperial representational buildings mark the crystallisation points in a profound, centuries-long recasting of the appearance of the city of Rome (Fig. 1). The cores consist of practically indestructible opus caementitium, faced with hard, quasi-industrially produced fired bricks. This construction method, later called opus testaceum, was uniquely suited to surviving the passage of time. For us today, this means that we have at our disposal an extraordinary wealth of evidence for the building construction methods used in those times. Given that even the building sites of classical antiquity were subject to market forces, the buildings are to be regarded as the outcome of rational decisions made on the basis of economy, durability and functionality. Particularly in the area of important imperial public buildings, where the pressure to be successful was exceptionally high, the conditions imposed by the market were certainly strictly observed. Large imperial building projects in which often many thousands of workers had to be organised and directed required the definition and implementation of standards applicable right across the site. To ensure the success of a major project these standards had to be laid down in series of technical regulations. The doctoral thesis on which the present paper is based examined the extent to which the organisation of large building sites influenced masonry constructions and whether, using the characteristics of the masonry that will be defined below, this influence can be read as a regulative on the erection of the structures.

The question of chronology
The existing methods of dating differ greatly in their precision and reliability. Scientific methods based on the examination of construction materials taken in situ from buildings focus on analysing phenomena and processes peculiar to the material character and composition of the building materials. As a rule they should all be approached with caution as regards dating: in many cases their dating relates to the time when the material examined was made and not directly to the period during which the building from which the mate-
rial was taken was erected. Here, precisely, lies the great appeal of dating-oriented analysis of brick masonry constructions: in comparison with building materials, masonry structures form so to speak the next, higher step in the process of creating a building. They are the building itself, or at the very least its essential and innermost core. If we can exploit this characteristic to arrive at a dating, then our results will reveal, very closely and directly, the point in time when a historic construction was built.

Problems in dating brickwork
If we view brickwork constructions as systems that, with their variations on an ideal model, practically make up the entire volume of a building, then we are confronted with an extensive and complex range of findings (Fig. 2). Not only can brickwork structures be read as the standard surface of a closed wall; they also display a variety of constructional details and with their core penetrate the third dimension of walls. Even if we succeed in fixing in time the canon of constructional possibilities of a certain building tradition on the basis of all the different variations used, the human inadequacies of those who carried out the work will still result in variations on this canon within certain accepted limits. Consequently strategies must be developed that define and describe the essential aspects of this enormous range of findings.

Present state of research
The number of important contributions to the dating of urban Roman *testaceum* brickwork is not very large. The first and original attempt was published in an article by the American archaeologist E.B. Van Deman (Van Deman 1912), which appeared in two parts. In a concise work based on an enormous knowledge of antique monuments gathered over a period of decades, the author succeeded in producing a first classification by epochs of *caementicum* constructions within which brick-faced masonry structures form the most important category. In her analysis of various masonry typologies and epochs, the author develops a nomenclature to describe the characteristics relevant to defining a chronology.

Thereafter the most important publication has been G. Lugli’s major work on Roman construction technology with its often lexically meticulous description of the technical aspects of Roman brickwork (Lugli 1957). Today’s experts are somewhat critical of his attempts, on the basis of just a few characteristics, to fix the dates for the various typologies of Roman brickwork structures. A quarter of a century later the work by T.L. Heres, *Paries: A Proposal for a Dating System of Late-Antique Masonry Structures in Rome and Ostia*, introduced an improved system of documentation into the discussion on methodology (Heres 1982). However, this work has a serious flaw in its method: although dated and undated masonry structures are distinguished from each other, the reader is left unsure whether and on what basis given datings are accepted or questioned, and how the dating system presented, which ultimately seems to operate on the basis of intuitive comparisons, can be used to anchor buildings securely to a particular point in time.

A number of subsequent works (Giulian 1990, 19-24; Cecchelli 2001) clearly betray reservations about the known masonry-based dating methods. M. Cecchelli, for example, in her informative and well-structured catalogue section on early
Christian masonry, restricts herself to compiling and documenting all data of relevance to the building structures, ranging from the historical sources through details of research history to examinations of masonry structures following a strict standard.

A breath of fresh air was introduced into the discussion by a research direction that has been developed with remarkable success since the 1970s under the name mensiochronology, which analyses dimensions and uses modern statistical methods to evaluate mediaeval and modern bricks (Fossati 1984; Mannoni and Milanese 1988). Although hardly any note has as yet been taken of it in classical archaeology, this interdisciplinary initiative has in many parts of Italy already provided numerically substantiated proof, based on the economics of construction, of a direct connection between the dimensions of the bricks examined and the time when they were made.

Aim of the study

The challenging aim of the study is to reconsider the problem of determining the chronology of specific examples of antique urban Roman brickwork — a group of examples of testaceum brickwork from the period between Diocletian and Constantine¹ that have already been given fixed dates using other methods — under new methodical preconditions and asking different questions. Comparison of the samples of brickwork examined demanded strict selection based on the following criteria: belonging to a single region, having been commissioned by comparable clients, use of the same masonry techniques, and reliable dating. After all, only if we prove that the assumed development over a continuous period of time did in fact leave a recognisable mark on individual buildings can we justifiably attempt to put hitherto inadequately dated brickwork into a proven chronological order.

Documentation standard for testaceum brickwork

Taking into account existing methods that combine a verbal, qualitative description of the building structures with measurements and examinations of their constructional elements and a photographic, in part also photogrammetrical, documentation of representative sections of the brickwork, a procedure was developed that combines a series of new processes from the fields of surveying technology, computer science and statistics with the familiar methods of recording and evaluating masonry data. It produces results that allow masonry structures to be characterized in a differentiated and objective manner.

Photogrammetry

In the course of the study it proved possible to show that the use of tacheometric-assisted methods of planar image rectification and cylindrical development (Fig. 3) allow entire areas of brickwork to be surveyed and documented, true-to-scale and with the real colours. For the first time in the history of the comparative examination of brickwork, these methods also allow the numerical recording and analysis of entire walls as constructional systems. As well as being able to be used at different scales, ranging from detailed to general overview, the plan material produced in this way allows larger areas to be dealt with, improves the statistical basis of the recording of data, and increases the transparency and verifiability of the entire documentation.

Fig. 3: Baths of Maxentius on the Palatine Hill, 307-312 A.D.: Rectified photograph of the substructures with mapping of the system characteristics, original scale of image 1:100.
Graphical evaluation
Whereas the true-to-scale graphical evaluation of the system characteristics can be carried out in the usual manner by mapping the photo-plans, the evaluation of the standard elements of the regular areas of brickwork – the brick and the mortar joints – is facilitated and accelerated by using a process developed in the research field of image analysis: \textit{semi-automatic, edge-precise segmenting} (Fig. 4). The method further developed for the questions examined here enables – like photogrammetry – large amounts of findings to be dealt with and thus also contributes to greater precision and reliability in the results of the examination. The further graphical development of the standard bond bricks in the rectified images has the advantage that these elements, along with their characteristics [height, length, shape], remain identifiable as \textit{individual pieces} and can be depicted in illustrations showing their salient features.

Automated evaluation of the characteristic values of the standard bond
The graphical isolation of the bricks in the rectified images allows their characteristic values to be evaluated automatically [\textit{extraction of characteristics}] and to be subsequently organised in tabular overviews. While this phase of the work meets the challenge posed by the large amounts of data, it also, and far more importantly, facilitates the identification of those parameters of bricks and mortar that can help answer the questions of building archaeology. In addition to the parameters of length and height that are generally required for each brick, further queries about characteristics can be defined. In addition to the \textit{calculated visible area} of a brick, the automated calculation of the pixels produces a value for its \textit{actual visible area}. Using the \textit{form factor}, which works out the extent to which the actual surface of the brick differs from an ideal rectangle, we may determine its \textit{degree of deformation} and for the first time give a value expressing the probability of a brick having been reused. The new method may well make it possible to establish other parameters defining the character of bricks.

Meaningful parameters can be defined not only for the element \textit{brick} but also for the representative sections of masonry \textit{per se}: by vertically and horizontally scanning the masonry images and with the help of new methods, the \textit{mean horizontal joint thickness} and \textit{vertical joint thickness} of a section of masonry can be determined with a high degree of reliability and accuracy. In areas of wall made up of bricks that have been recycled these values could not yet be measured by hand, as the imprecise values obtained differed too widely. The spread of these two parameters within a defined measured area also allows objective statements about the inhomogeneity of the brick material examined and about the extent to which it was reused. Using this knowledge of the actual areas of brick and mortar surfaces in a defined section of brickwork, it is possible to work out area-related values for the \textit{proportion of brick} and the \textit{proportion of mortar} in the section of wall. These parameters also represent something entirely new in the field of brickwork examination in that they can be used to establish precise surface values in the materials used on a given building site.

Manual evaluation of the characteristic values of special construction elements
Evaluating special constructional elements of a masonry bond – such as the bonding courses, scaffolding courses, openings and masonry arches –
represents a second area for the derivation of masonry parameters (Fig. 3). It is based on the high-resolution photogrammetrical plan material produced at overview scale. As well as allowing a better handling of existing parameters, it also permits the definition of masonry characteristics that are either entirely new or that have so far only been partially numerically defined. So, for example, the characteristic of the mean course height, which determines the vertically measured denseness of the brick courses could, thanks to the possibility of making a continuous measurement of all brick courses in a defined area, be increased to a certainty level of 100%. In addition, constructional elements such as the bonding courses and scaffolding courses [along with the vertical distances between them], which structure the building process in a special way, could be introduced as new, numerically recorded and therefore highly accurate system characteristics. The information provided by this group of characteristics proved particularly significant in defining a building chronology in the area under examination.

Statistical calculation methods
Through the use of statistical methods it was possible to calculate a series of standard [specific] values for the individual characteristics, allowing a considerable increase in the reliability and precision of information conveyed by the values.

Building catalogue
The results of the examinations of masonry carried out at selected building sites from the relevant period were compiled in a catalogue consisting of ten building-based sections, and were compared with the historical and archaeological source material required for identifying and dating the masonry. The characteristics and values of the examination parameters depicted here in systematic form present the building site standard that characterizes the individual buildings, and allow direct comparisons of the brickwork examined to be made.

Reconstructing the chronology of the brickwork structures examined
After all the buildings [building sites] had been systematically recorded in the manner described above and classified according to the occurrence of the masonry characteristics retrieved, the values calculated were organised in a table. Correlating the data with the factor time made it possible to follow the development of the values during the period covered by this study [298-345 A.D.]. This also allowed unimportant characteristics to be distinguished from important ones.

Brick lengths and heights
One hardly surprising result of the study is that the parameters usually sought in comparative examinations of masonry, brick length and brick height, say hardly anything about developments during the period covered by the study (Fig. 5). As the spread of both characteristics in all the buildings examined is very high, it can be safely assumed that a homogenous brick material from a contemporary production source is not dominant in any of the cases examined.

Proportion of mortar
By contrast, all the parameters relating to joint mortar have shown clear development tendencies, which in the period between the earliest Diocletian building in Rome, the Curia Iulia, and the late Constantinian Mausoleum of Constantina reveal a perceptible increase in the relative amount of mortar used in brick faces. The results of the study reveal that the surface-related proportion
of mortar in the Diocletian era was in the range 32-46%, under Maxentius 45-51%, and in the Constantinian buildings as high as 50-55%.4

Height of the horizontal joints
The development of the values for the height of the horizontal joints is even steadier and therefore, given the current data situation, even more suitable for defining a chronology (Fig. 6). The Diocletian buildings have horizontal joints measuring 1.4-2.2cm in height, the large Maxentian inner city projects have joints with a constant height of 2.4cm, and from the last of the Maxentian projects to all the Constantinian building sites the joint height increases further to 2.6-2.7cm5.

Course heights
With relatively constant brick heights, the material reveals a for the most part highly informative development as regards the characteristic course height – including brick and horizontal mortar bond. Whereas Diocletian course heights are on average 5.2-5.7cm, and the three Maxentian large inner city projects have courses with an average height of 6cm from the Mausoleum of Maxentius erected in the late Maxentian era to the top storey of the Mausoleum of Constantina the figure increases to 6.2-6.6cm.

System parameters
A second group of masonry characteristics first used systematically in the course of this study shows in an equally clear manner the development of the opus testaceum in the period under review from Diocletian to Constantine. In the group of system parameters it was in particular the characteristics distance between bonding courses, distance between scaffolding courses and combination of bonding and scaffolding courses that were able to provide a numerical description of the building chronology (Fig. 7).

Bonding courses
Whereas in the Curia Iulia we can recognise a standard and clearly consciously intended vertical distance between the bonding courses of somewhat more than 4¼ ft [4.34 RF = 128.5cm], in the period between the erection of the Baths of
Diocletian and the Mausoleum of Maxentius this value oscillates in the range 5-5¼ ft [4.90-5.29 RF = 145.0-156.5cm], with the figure approximating closely to five ft [4.98 RF = 147.5cm] in five of the six buildings concerned. In the only Constantinian building in which, with some reservations, we can talk of a standard distance aimed for in 50% of the cases, the mean distance between the bonding courses is by contrast somewhat more than 5½ ft [5.56 RF = 164.5cm].

**Distance between the scaffolding courses**

The **distance between scaffolding courses** reveals a similar picture: in the Maxentian period the standard distance was almost exactly five ft [5.05 RF = 149.5cm]. The enclosing walls of the Baths of Diocletian [5.14 RF] and the Mausoleum of Helena [4.98 RF], which mark the start and end of this period, can also be allotted to this group of buildings, whereas before and after this core period the mean distance between scaffolding platforms is exactly 5¼ ft.

The two system parameters of **distance between bonding courses** and **distance between scaffolding courses** also describe a core area in which the mean standard interval lies very close to five ft. In the case of the distance between bonding courses this period can be extended backward to include the central building of the Baths of Diocletian, while with respect to the distance between scaffolding platforms it can be extended forwards to include the Mausoleum of Helena. If the enclosing walls of the Baths of Diocletian are included in this era, the overlapping area of the two core periods exactly matches the Maxentian construction period, during which both parameters reached a mean figure of precisely five ft, while at the same time the number of distances that clearly exceed this standard figure decreases to a minimum.

**Combination of bonding courses and scaffolding courses**

What these figures describe – namely a complete convergence of the two system distances governing the construction process – is confirmed in practice: the logical regular combination of the system courses at intervals of five ft can only be identified and proven in the Maxentian construction period. If we follow this system parameter of a **combination of bonding courses and scaffolding courses**, not only do the four Maxentian buildings but also the enclosing walls of the Baths of Diocletian belong to the core period of the study. All other buildings follow different systems. For instance, the standard in the Constantinian buildings examined reveals an efficient method in which bonding courses are used only where special demands of the construction require them, which was thus clearly an attempt to establish a universal, statics-based kind of structural design.

**Maxentian building standard**

However, the Maxentian standard goes far beyond guidelines determined solely by structural requirements. The system used between 306 and 312 A.D. betrays the pursuit of a building process that could be checked at any time throughout the building site and that through the regular and combined use of the two different system courses was calculated to impose on the growing building a rhythm clearly visible to all involved in the construction work. As this new standard made it easier than ever before to coordinate the many different groups of workers in order to meet certain fixed interim goals, it may be regarded as having been the fruit of experience and a conscious attempt to increase the efficiency of building site organisation. Amongst the building sites where this standard is employed, the outer precinct of the Baths of Diocletian, probably the earliest fourth-century example of that building standard, was clearly an area of experiment for the new procedure. A short time later, presumably following the seamless re-engagement of the building firms and architects who erected the baths, what emerged here as a highly promising form of organisation, structuring the building process and shortening the construction period, was to be brought to perfection in the large representational buildings of Maxentius.

**Acknowledgements**

I should like to express my heartfelt thanks to the supervisors of my dissertation, Prof. Dr. Marina Döring-Williams and Prof. Dr. Johannes Cramer, who as experts in the Roman subject matter were invaluable discussion partners.
Notes


2. For example work on a rotation factor has been started that shows the position of a brick in its mortar bed; a value that allows important statements to be made about the horizontality of the bricks in the course.

3. These brick courses are marked by holes in which the timbers that supported the scaffolding used in erecting the walls were once fixed.

4. Here once again the value of the Curia Julia appears important, which with a proportion of mortar amounting to only 32% is far below that of all other buildings.

5. This characteristic – just like the proportion of mortar above – also shows that as regards the way they are built the Baths of Diocletian are far more similar to the Maxentian buildings than to the Diocletian Curia Julia, which has horizontal joints 1.4cm thick, a figures far below that of all other buildings.

6. An extensive discussion on a possible late dating of this second phase of construction of the Baths can be found in Esser 2008, 188–206 in Chapter 4.2 “Diokletiansthermen.”

7. The same standard was achieved a century earlier in the construction of the Baths of Caracalla starting from 212 A.D. This must however have been forgotten in the intervening period, as there was probably no documentation of the way the building site was organized.

Reference list


# Complete Table of Contents

**Volume 1**

*On Construction History, Robert Carvais, André Guillerme, Valérie Nègre, Joël Sakarovitch.......................................... IX*

## 1. CONSTRUCTION HISTORY, A FIELD OF STUDY

- **Epistemology & Historiography**
  - **Analyzing Historical Timber Structures**
    - *A Case Study on Ernst Gladbach [1812–1896] and His Research on the “Swiss Style”, Knut Stegmann*.................................................. 3
  - **Ethnographic Studies and Their Contribution to Construction History in Portugal**, João Mascarenhas-Mateus........................................ 11
  - *The Science of Building as a Polytechnic Discipline in the 19th Century*, Torsten Meyer............................................................... 21
  - **Architectural Anthropology: A Knowledge-Based Approach**, Sascha Roesler ......................... 29

- **Sources & Methods**
  - **Mesopotamian Foundation Deposits in the Louvre Museum**, Amparo Graciani ......................... 37
  - **The Study of Medieval Lifting Machines Thanks to Iconography: An Example in Mediterranean Machinery**, Lorena Fernández Correas........ 45
  - **A Study on the Traditional Production of Lime: The Role of Oral Sources**, Rita Vecchiattini, Giovanni L.A. Pesce.............................. 53
  - **Integrated Methods for the Study of Construction Techniques**, Mariachiara Faliva ................... 69

- **Education & Diffusion**
  - **Construction of a Pendentive Grid Crossing Vault**, José Carlos Palacios Gonzalo, Sandra Cynthia Bravo Guerrero ......................... 81
  - **Maillart’s Practices for Structural Design [ETH-Bibliothek's Virtual Exhibition]**, Denis Zastavni .................................................... 89
  - **The Nervi System: A Model-Game to Understand**, Tullia Iori, Sergio Poretti .... 97
  - **CH.E.S.S: European Summer Schools on Construction History**, Werner Lorenz, Roland May ........... 105

- **Heritage & Restoration**
  - **Use of Modern Materials in the Conservation of Traditional African Buildings**, Ishanlosen Odiaua, Abraham A. Taiwo, Rosemary Ajayi ........................................ 113
  - **The Interpretation of Palladio’s Building Techniques: Palazzo Chiericati and the Restorations of the 19th Century**, Damiana Lucia Paternò ................. 121
2. KNOWLEDGE & THEORIZATION

– Architectural & Structural Design

Toward an Iconography of Stereotomy, Richard A. Etlin ..................................................... 145

Builders’ Inventiveness in Madrid’s Baroque Convents: Construction Invariables, María Antón Barco, Eva J. Rodríguez Romero, Juan Tejela Juez ................................................................. 155

The Narthex Vaults of the Church of Saint-Germain-l’Auxerrois in Paris, Dominic Boulerice.................................................... 163

The First Complete List of All the Models Made for the Construction of St. Paul’s Cathedral, London 1675-1720, James W.P. Campbell ................................................................. 173

Nineteenth Century Invention under Scrutiny: Louis Auguste Boileau’s Frame Construction Systems of around 1850, Laurent Koetz ......... 185

The Science of the Beautiful: S.C. Constant-Dufeux and the Parabola as Constructive and Symbolic Form, Ralph Ghoche ......................... 193

The Development of Design Charts and Other Graphical Calculation Tools for Use by Building and Civil Engineers up to the Early 20th Century, Bill Addis ...... 201

Modern Interpretations of the Vernacular Tradition in the Work of J.A. Coderch 1940-1964, Ana Rodríguez García ..................... 211

– Applied Sciences

Firmitas and the Status of the Laws of Statics and Mechanics, Sara Franceschelli, Antonella Mastrorilli ........................................ 221

Some Aspects of John Wallis’s Structural Mechanics, François Fleury ...................... 229

Newtonian Scientists on the Relation between a Catenary Curve and an Arch Supported by its Own Weight, Patricia Radelet-De Grave ......... 237

Curves Mastery at the Royal Academy of Architecture: The Case of Jules Hardouin-Mansart, Luc Tamborero ........................ 243

Guarini’s Flat Vaults and Thin Vaults on Wooden Beams in the Duchy of Modena, Alberto Grimoldi ........................................ 249

The Role of Stereotomy in Guarino Guarini’s Space Research, Carlo Bianchini .................... 257

Theory and Practice in Timber Construction 1800-1830, Andreas Kahlow .................. 265

Same Title, New Contents: Saint-Venant’s Revised Edition [1864] of Navier’s Résumé Des Leçons Sur L’application De La Mécanique [1826, 1833], Federico Foce ......................... 273

– Structural Analysis & Modeling

The Membrane Analysis of Thin Masonry Shells, Jacques Heyman ............................. 281

The Temple of Diana at Baiae: History and Structure of an Imperial Roman Dome, Timothy Cooke, John Ochsendorf .................. 291

On the As-Built Geometry of the Vaults of the Basilica of Maxentius, Alejandra Albuerné, Martin Williams, Janet Delaine .. 299

Structural and Constructive Analysis of the Acequia Real Aqueduct in the Alhambra, Granada, Javier Suárez, Laura Cirera .......... 307
The Islamic Crossed-Arch Domes in Cordoba: Geometry and Structural Analysis of the “Capilla de Villaviciosa”, Paula Fuentes .................... 317

The Minaret of the Mosque of Mansourah: A Half-Ruin Elucidated, Fouad Ghomari .... 325

Structural Devices Concerning the Progressive Outer Shell Construction in Brunelleschi’s Dome, Maria Teresa Como ................................... 331

The Ciborium or Lantern Tower of Valencia Cathedral: Geometry, Construction and Stability, José Antonio García Ares, Ignacio Javier Gil Crespo ..................... 341

Arches and Spirals: The Geometrical Concept of the Curvilinear Rib Vault in the Albrechtsburg at Meissen and Some Considerations on the Construction of Late-Gothic Vaults with Double-Curved Ribs, David Wendland ... 351

An Insight into Abeille's Flat Vault through Numerical Analyses, Maurizio Brocato, Lucia Mondadini .................. 359

Analysis of Philippe de la Hire’s Arch Theory Using Graphic Statics, Thierry Ciblac......... 367

Structural Analysis of Thin Tile Vaults and Domes: The Inner Oval Dome of the Basilica de la Virgen de los Desamparados in Valencia, Santiago Huerta ......................... 375

– Transfer of Knowledge


Transmission of Building Technology from Europe to the Americas: Underlying Geometry and Stereotomy Studies of Three Ribbed Vaults Constructed in Mexico between 1535 and 1575, Benjamin Ibarra-Sevilla ............. 393

'Machine pour ouvrir une fenêtre par contre-poids': A Case Study Revealing the Nature of Invention and Innovation in Late 17th Century Northern European Architecture, Hentie Louw ................................. 401

Knowledge of Architecture and Building Technologies in 18th Century Sweden, Linnéa Rollenhagen Tilly ......................... 409

Early Iron Bridge Construction for the Grand Duchy of Baden and for Central Europe, Martin Trautz, Friedmar Voormann ........ 419

Traces of Construction Following Migration: Transverse Gable; Massive Timber and Carpenter's Marks in the Houses of the 19th Century German Settlers in Southern Chile, Francisco Prado, María F. Vargas, Renato D’Alençon, Daniel Korwan, Johanna Moser ......... 429

Technical Supremacy: Tropical Architecture and Technologies of the British State, Alexandra Quantrill............................. 439

The Roots of Foreign Effects in Development of the Turkish Construction Sector [1719-1933], Hilal Tuğba Örmecioglu, Bilge Küçükdoğan, Aslı Er Akan ........ 449

A Study of Military Facility Planning from the Viewpoint of Technological Transfer from France to Japan, Rüichi Miyake, Michiko Maejima .................. 457

The Developmental Procedure of the Traditional Architectural Woodworking Tools in Taiwan, Bo-Hsun Yao, Min-Fu Hsu ......................... 465

– Rules & Standards

For a Comparative Study of Construction Laws, Robert Carvais .............................. 475

The Architecture pratique by Pierre Bullet [1691] and the Normalisation of the Construction Process, Juliette Hernu-Bélaud .................. 489

The Structure of Houses in Madrid 1669-1900: Buildings and Documents, Esperanza González Redondo .................. 503

History of Construction in the 18th Century through the “Istruzioni” Written by Filippo Juvarra, Beatrice Maria Fracchia .................. 513

Contractors of 19th-Century Public Works in Belgium: Looking for a Research Approach for the Rural Areas, Jeroen Cornilly ............... 519

Limitations Stemming from the Legal Regulation of Designs of Foreign Architects in Spain in the 19th Century: The Case of the Basque Country, María Teresa Paliza Monduate ....... 527

The First Building Code of Campinas – 1934: A Legal Instrument of the Urban Modernization Process of the City, Silvia Amaral Palazzi Zakia .......................................................... 537

– Training & Education

Teaching Construction in the Académie Royale d'Architecture, Hélène Rousteau-Chambon.......... 545

Oral Transmission and the Use of Models in the Teaching of Architecture and Construction at the Turn of the 19th Century, Valérie Nègre .................. 555

How Belgian Engineers Passed on Their Knowledge between 1830 and 1865: Education, Association and Publication, Willemijn Linssen, Krista De Jonge .......... 565

Short of Education or Short of Engineers: British Civil Engineering 1890-1910, Mike Chrimes .................. 575

The Italian Engineers’ Architecture and Technique Training, Simona Talenti .... 587

“Purpose” and “Means” of Architectural Design: Construction in Julien Guadet’s Teachings in Architectural Theory, Guy Lambert .......... 595

– Technical Literature & Drawings

“De Fenestris”: An Unpublished Treatise from the Mid-15th Century on the Construction of Windows and Stained Glass, Paola Travaglio .......................................................... 603

Moving St. Peter’s Obelisk as Seen in the Engravings of Giovanni Guerra and Natale Bonifacio: A Transmission of Knowledge, or Pure Propaganda?, Maria Grazia D’Amelio .................................................. 611

Guidohaldo del Monte as Architect and the Construction of Santa Maria degli Angeli in Pesaro, Francesco Menchetti, Laura S. Pelissetti .................................................. 621

An Unpublished Treatise on Waters by Vincenzo Della Greca: A Source of Carlo Fontana’s Utilissimo Trattato Delle Acque Correnti, Marisa Tabarrini .......................................................... 629

George Semple and the Reconstruction of Essex Bridge in Dublin 1753-1755, Dermot O’Dwyer, Ronald Cox .................. 637

The Squinch Vaults in Joseph Ribe’s Llibre De Trasas De Vias Y Muntea, Fabio Tellia, Jose Carlos Palacios Gonzalo .................. 647

Hokusai Manga as a Reference Construction Book, Jean-Sébastien Cluzel .... 655

A Review of the Depiction of Ancient Construction by Charles Chipiez in L’Histoire De l’Art, Javier Girón .................. 665

Construing Construction with Drawings: Robert Willis’ and Auguste Choisy’s Axonometric Representations of Vaulted Structures, Hilary Bryon .......................................................... 673

Handbooks on Construction Site Supervision in the 19th Century, Christoph Rauhut .......... 683
Volume 2

3. PEOPLE & ORGANIZATIONS

– Craftsmanship & Technical Tasks
Metropolitan Vernacular: On the History of Informal Construction in a Brazilian City, Silke Kapp, Ana Paula Baltazar............... 3
A Case Study of Local Builders’ Carpentry Tools: Traditional Constructions of Ürünlü, Turkey, Gülşah Çelik, Kemal Reha Kavas... 11
Building Construction in Medieval Spain: The Female Perspective, Shelley E. Roff ...... 17
Building Culture and Competence: Demonstrating Knowledge on Construction Sites in 18th-Century Virginia, Elizabeth Cook.......................... 23
Building Trades in Catalonia during the Modern Era: The Case of Immigration to Girona City, Gemma Domènech Casadevall........ 31
From Master Mason to Architect: James Smith’s Construction Techniques at the End of 17th Century in Scotland, Cristina González-Longo, Dimitris Theodossopoulos ............... 37
Barbetti Serafin: Builder of Vaulted Bridges in South-Western Colombia [c. XIX], Jorge Galindo Díaz................................. 47
Who Paints the House? Scotswomen as Housepainters and Decorators from 1820, Nina Baker................................. 53

– Contractors & the Labor Market
Private Archives of the 18th and 19th Centuries: Sources for the History of Marble-Working in Belgium, Joëlle Petit........ 73
The Development of Belgian Ironworks in the 19th Century: Case Studies and Reflections on Sources and Historiography, Koen Verswijver, Inge Bertels, Ine Wouters, Quentin Collette........................................ 81
Architecture and Reinforced Concrete in Brazil: The Action of the Largest Construction Companies in Brazil, Christiani & Nielsen and Ways & Freytag, Maria Luiza de Freitas............................... 91
Building Modern Spain: Some Notes on Huarte y Cía, Javier Martinez-Gonzalez, Marta García-Alonso .................................. 99
The Significance of Building Labour to the Production of the Built Environment, Linda Clarke, Charlie McGuire, Christine Wall........................................... 107
Construction Work in Four German States: Before, during and after the Cold War, Jörn Janssen, Ernst-Ludwig Laux...................... 115
Concrete Constructors: Oral History Accounts of Building Work on a Large, Complex Site in 1960s Britain, Christine Wall, Linda Clarke, Charlie McGuire.............................. 125

– Organization of the Construction Site
Construction Methods in Carolingian Rome [Eighth-Ninth Centuries], Lia Barelli............... 135
Building during the War of Granada: The Project for Reconstructing Fuengirola in 1485, Raúl Romero Medina, Manuel Romero Bejarano.................................................. 145
Building the New Prisons of Venice and Their Bridge [1591-1604], Andrea Bonavita....... 149
The Building of the Arsenal of Le Havre in the 17th and 18th Centuries, Matthieu Pinon................................. 157
Road Construction Sites in 18th Century France: Labor and Administration in Action, Anne Conchon, Katherine McDonough .... 165
Reconsidering the “Considerable Expense” Involved in Building the Lavaur Bridge in Languedoc [1769-1791], Catherine Isaac.... 173
Innovation and Tradition in the Reconstruction of the Basilica of St. Paul Outside the Walls in Rome [1825-1928]: Technologies, Procedures, Protagonists, Nicoletta Marconi..... 181
The Builder’s Flying Squads: An Analysis of the Ministry of Works Special Repair Service Activities during WWII, Richard Burt ....... 191
Analysis of the Construction Site as a Historical Document of Its Production Process, Carolina Heldt D’Almeida ........... 199
Managing the Design and Construction of the Empire State Building: Are There Lessons for Today’s Projects?, Kenneth F. Robson...... 207
The Avianca Tower: Practices Driving Technical Innovations in a Construction Firm in the 60s, Camilo Villate,
Brando Tamayo .............................................. 217

– Property & the Real Estate Market

The Role of the Islamic Pious Foundations [Waqf] in Building the Old City of Jerusalem during the Islamic Periods [637-1917], Musa Sroor.......................... 229
Between Market and Architecture: The College of Engineers, Architects and Land Surveyors in Real Estate Pricing in 16th-18th Century Milan, Michela Barbot ................................. 237
Building Expropriation Process for the Construction of the New Dock at the Port of Cartagena [Spain] in the 18th Century, Gema Ramírez Pacheco, Federico García Erviti, María Jesús Peñalver Martínez, Juan Francisco Maciá Sánchez.............. 245
Changing Patterns in Residential Construction and the Real Estate Market: Spain, 1910-1960, Miguel Artola Blanco ... 255

Urban Dynamics and Horizontal Property: Case Study of the Boavista Axis, Porto, Portugal, Clara Pimenta do Vale, Vitor Trindade Abrantes ...................... 265

– Institutions

The Great Hall of the Institution of Civil Engineers Headquarters Building, Malcolm Dunkeld.............................. 273
An Institution for Structural Innovation: Office for the Study and Design of Industrial Building Types [BISTYP] in Postwar Poland, Alicja Gzowska .......... 281
Brazilian Construction Center: Initiative for Management of the Brazilian Housing Construction Industry [1969-1972], Ana Paula Koury..... 289
Construction Material Testing at MPA Stuttgart during the Third Reich, Christiane Weber........ 297

– Politics & Policies

Construction Financing in Late Medieval Portuguese Towns [14th-16th Centuries], Arnaldo Melo, Maria do Carmo Ribeiro .... 305
Research and Construction in the Late Colonial Settings: Institutions, Technology and Development Programs in Africa, 1948-1958, Hélène Vacher, ........................ 313
The Plot of Concrete in Brazil: A History of the Technology Diffusion of Reinforced Concrete, Roberto Eustaáquio dos Santos... 323
Conceiving the Industrialization of Construction in France in the 1950s, Christel Frapier ................................. 337
Construction of Railway Workshops in Colombia during the First Half of the 20th Century: A National Engineering Triumph, Ricardo Tolosa, Jorge Galindo Díaz........... 345
## 4. MATERIALS

### Earth, Bricks & Tiles

- **Earththen Building Techniques in the Humid Tropics: The Archaeological Site of La Joya, Veracruz, México,** Annick Daneels, Luis Fernando Guerrero-Baca .......................... 353
- **Persistence of the Perishable; Wattle-and-Daub Architectures in the Roman Period: A Census of the Archaeological Findings in Gallia Cisalpina and the Case of Mediolanum,** Anna Antonini ......................... 361
- **Efficiency in Form: Thomas Jefferson’s Serpentine Walls at the University of Virginia,** Jennifer Zessin, John Ochsendorf ................................. 375
- **Three Key Aspects of the History of Brick Construction in Scotland,** Moses Jenkins ......................... 383
- **Marseilles Tile,** Miles Lewis .............................. 391
- **Against Replication: Carved Brick at the Dawn of the Terracotta Age,** Sara Wermiel .......................... 401
- **Structural Morphology Presented on Surface Cladding: From Structural Brick to Ornamental Tile in the Westernised Far East,** Nan-Wei Wu .............................. 409
- **Load-Bearing Wall Structures in the Works of Lluís Nadal,** Gemma Muñoz Soria ...................... 417

### Stone

- **The Aeolian-Style Polygonal Masonry in Larisa [Buruncuk] and its Regional Context,** Turgut Saner, Kaan Sağ .................................. 427
- **Stone Cladding Techniques in French Modern Architecture [1920-1940],** Angelo Bertolazzi ............................... 443

### Reuse

- **For a History of Deconstruction,** Philippe Bernardi, Daniela Esposito .......................... 453
- **The Use of the “Already There”: Reuse and Recycling for Monumental Building in the West in Late Antiquity and the Medieval Period,** Stéphane Büttner ......................... 461
- **The Use of Granite Columns in Rome, 15th-16th Centuries,** Emanuela Montelli .......................... 481
- **The Revival of Classical Building Techniques in Late Ottoman Architecture in Bergama, Turkey,** Martin Bachmann ............................. 491
- **A Study on Distribution and Reuse of Tram Line Paving Stones in Japan,** Sachiko Okada, Ichiro Kobayashi, Koichi Nakama ........................................ 501

### Plaster & Mortar

- **Traditional Structures Made with Gypsum Pillars: A Reasoned Hypothesis,** Fernando Vegas, Camilla Mileto, Maria Diodato, José García Soriano, Carles Grau Giménez ................. 509
- **Geological Origin of the Reagents Constituting Roman Mortar, According to Vitruvius,** Frédéric Davodvits ........................................ 517
- **The First Verifiable Application of Cast Mortar in Prefabricated Construction in the Coffered Ceiling of the Early Hellenistic Mausoleum of Belevi,** Reinhard Heinz ...................... 523
- **The Use of Mortar in Late Hellenistic Construction: The Case of the Octagon in Ephesus,** Barbara Thuswaldner .......................... 531
The Knowledge and the Development of Mortars between the 18th and 19th Centuries: The Case Study of the Verona Amphitheatre Restoration, Marco Cofani ........................................ 539

History and Technique of an Italian Wooden Floor System Based on Reeds and Gypsum Plaster Frames: The Case of Reggio Emilia, Luca Boiardi, Maria Regina Tedeschini, Riccardo Gulli ........................................ 549

– Metal

The Role of Iron Armatures in Gothic Constructions: Reinforcement, Consolidation or Commissioner’s Choice, Maxime L’Héritier, Philippe Dillmann, Arnaud Timbert, Philippe Bernardi ........................................... 557

A Victorian Ironworld: Cast Iron, Ornament and Brighton, Paul Dobraszczyk .... 565

– Reinforced Concrete

François Hennebique’s Patents as Applied on the Building Site: The Mercato Orientale in Genoa [1896-1899] and the Creation of a Local Construction Network, Hermann Schlimme ........................................ 573

Concrete Piling: Major Developments in the Historical Practice of Pile Foundations, Armande Hellebois, Yves Rammer, Jean-Claude Verbrugge, ........................................ 583

Béton Armé in a Sinking City: Mexico 1902-1914, Mónica Silva-Conteras ..................... 593

Technological Innovation and Traditional Building Methods in the First Application of Reinforced Concrete in L’Aquila: The “New Provincial Insane Asylum” [1903-1916], Alessandra Bellicoso ..................... 601


Reinforced and Prestressed Concrete in High-Rise Construction in Spain, 1950-1975: Technique and Innovation, Jesús Anaya Díaz ..................... 619

The Transformation of Construction by Concrete, Andrew Rabeneck, .................... 627

The ‘Scientification’ of Reinforced Concrete in Belgium during the Interwar Period: Development and Dissemination of Scientific, Theoretical and Technical Knowledge, Stephanie Van de Voorde, Rika Devos ...... 637


Air Raid Shelters in the United Kingdom 1939-1945: An Initial Investigation, John McGuinness .......................... 657

Volume 3

5. TECHNOLOGY

– Foundations & Masonry

The Achievement of Structural Stability in the Drystone Iron-Age Broch Towers in North Scotland, Dimitris Theodossopoulos, John Barber, Graeme Cavers, Andy Heald .... 3

Masonry Constructions as Built Archives: An Innovative Analytical Approach

Opus Testaceum Brickwork in Rome, Gerold Eßer .......................... 13

The Scaenae Frons of the Roman Theatre of Italica: Notes on the Construction Process, Francisco Pinto Puerto, José María Guerrero Vega .......................... 21

Foundation Techniques in the Early Modern Low Countries [1600-1750]: A Problematic
<table>
<thead>
<tr>
<th>Topic</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Case – St. Walpurgis in Antwerp</strong></td>
<td>Maud De Voght, Krista De Jonge</td>
</tr>
<tr>
<td><strong>The Pentagon Ramparts and Bastions of Fortress Rosenberg in Kronach, Germany</strong></td>
<td>Philip S.C. Caston</td>
</tr>
<tr>
<td><strong>– Vaults &amp; Stereotomy</strong></td>
<td></td>
</tr>
<tr>
<td>Opus revinctum in Dome and Barrel Vault Constructions in Roman Asia Minor, Ursula Quatember, Barbara Thuswaldner</td>
<td>45</td>
</tr>
<tr>
<td>Construction of Early Rib-Vaults in Croatia</td>
<td>Marina Šimunić Buršić</td>
</tr>
<tr>
<td><em>The Chambiges and the Construction of Vaulted Stone Spiral Staircases</em></td>
<td>Alberto Sanjurjo Álvarez</td>
</tr>
<tr>
<td><em>The Irregular Ribbed Vault of the Sacristy of the Cathedral of Saint-Jean Baptiste in Perpignan</em></td>
<td>Rosa Senent Domínguez, Miguel Ángel Alonso Rodríguez, Enrique Rabasa Díaz</td>
</tr>
<tr>
<td>Late German Gothic Methods of Vault Design and Their Relationships with Spanish Ribbed Vaults</td>
<td>Rafael Martin, Talaverano, Carmen Pérez, de los Ríos, Rosa Senent Domínguez</td>
</tr>
<tr>
<td>Safavid Ribbed Vaults as a Masterpiece of Iranian Construction Techniques</td>
<td>Stefánia Petrala</td>
</tr>
<tr>
<td><em>The Lecce Vault: History, Construction Techniques and New Design Perspectives</em></td>
<td>Giuseppe Fallacara</td>
</tr>
<tr>
<td><strong>– Shells &amp; Thin Vaults</strong></td>
<td></td>
</tr>
<tr>
<td>Tests on Tile Vaults in France in the 19th Century</td>
<td>Esther Redondo Martínez</td>
</tr>
<tr>
<td>Pioneer Concrete Shells in Spanish Architecture: The Innovation System-Design of Ildefonso Sánchez del Río</td>
<td>Pepa Cassinello</td>
</tr>
<tr>
<td>James Hardress de Warenne Waller and His Contribution to Shell Roof Construction</td>
<td>Ciarán Conlon</td>
</tr>
<tr>
<td>Shell Wars: Franz Dischinger and Ulrich Finsterwalder, Roland May</td>
<td></td>
</tr>
<tr>
<td>Reinforced Concrete Shells in Estonia during the Soviet Period: Science and Practice</td>
<td>Maris Suits</td>
</tr>
<tr>
<td><strong>– Wood Structures</strong></td>
<td></td>
</tr>
<tr>
<td>A Roof under One’s Feet: Early Neolithic Roof Constructions at Göbekli Tepe, Southeastern Turkey</td>
<td>Dietmar Kurapkat</td>
</tr>
<tr>
<td>Fan-Shaped Bracket Sets and Their Application in Different Building Materials: A Discussion of the Chinese Fangmu Tradition and Jin-dynasty Tomb Architecture in Southwest Shanxi Province</td>
<td>Alexandra Harrer</td>
</tr>
<tr>
<td>Medieval Timber Structures in Eastern Germany: Archaeological Evidence from Eberswalde</td>
<td>Christof Krauskopf</td>
</tr>
<tr>
<td>Commercial Categories and Applications of Construction Timber in the Trentino-Verona Area [14th-16th Centuries]</td>
<td>Silvia Dandria</td>
</tr>
</tbody>
</table>
Nuts & Bolts of Construction History

Wooden 'Italian' Wide-Span Roofs of German 19th Century Theatre Buildings, Anja Wünnemann, Stefan M. Holzer, Clemens Voigts............................ 193

– Metal Structures

Rebuilding St. Petersburg's Winter Palace in the Context of Early European Steel Structures 1838-1850s: Contemporary Sources and Documents, Sergej Fedorov ................. 203

Two Crystal Palaces: Constructive Technology and Practice; Great Britain 1851 – United States 1853, Donald Friedman, Brian Bowen................................................... 215

Wrought Iron and Steel Structures in Berlin in Their Prime from 1875 to 1925, with a Focus on Buildings for the Arts, Ines Prokop................................................... 225

A Prefabricated Cast Iron Three-Hinged Arch Bridge in Ljubljana, Lara Slivnik........... 235

Historic Bridge Bearings: Material Research on Cast Steel, Volker Wetzk.......................... 243

The Vierendeel Bridge at its Heyday: Rational Design, Experiments and Brittle Failure, Bernard Espion................................................. 253

– Interior Environment & Energy

Heated Vaulting in Roman Britain and the Invention of Hollow Terracotta Voussoirs, Lynne C. Lancaster ......................... 261

The Stube: Constructive Evidence for the Concept of a Smoke-Free Heated Living Room between the Alps and Southern Scandinavia, Rainer Arzbach................................................. 269

The Construction and Integration of Historic Heating Systems in Churches in the United Kingdom from the 17th to the Early 20th Century, Spyridon Papavasileiou, Magdalini Makrodimitri, James Campbell..... 277

Comfort versus Industry: Maintenance of the Royal Palaces of Milan during the 1860s, Carlo Manfredi....................... 289

The Military Engineers and Hygiene in Barracks in the Second Half of the 19th Century, Francesca Turri, Emanuele Zamperini ...... 299

Scientific Developments of Heating and Ventilation Professional Unions and Learned Societies in France during the First Part of the 20th Century, Emmanuelle Gallo ....... 309

Innovations in Ventilation: Wind Cowls in the 19th Century, Maike van der Tempel, Ine Wouters, Filip Descamps, Dorien Aerts................................. 317

Hygiene in Belgian Architecture: The Case of Victor Horta [1861-1947], Dirk Van de Vijver..................... 325

Artificial Light in the Aristocratic Palaces in the Po Valley between the 17th and 18th Centuries, Laura Balboni, Paolo Corradini, Angelo Landi.................................................. 333

Artificial Light in Architecture in France and Italy during the First Years of the 20th Century: From Gas Light to Electric Light, Giulio Sampaoli............................................. 341

The World Health Organization Headquarters in Geneva [1960-1966]: How Mechanical and Electrical Services are Integral to Reading Built Form, Giulia Marino................................. 351

The Morphological Evolution of the Vertical Axle Windmill between the Second and the 18th Centuries A.D., Kambiz Mosthtaghe Gohari................................. 359

Constructing a Solar House, c. 1959, Daniel A. Barber ........................................... 367

The Thermal Insulation of Facades after the Oil Crisis of 1974 to the 80s, Samaher Wannous......................... 379
## Prefabrication & Industrialization

<table>
<thead>
<tr>
<th>Title</th>
<th>Author(s)</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-War Industrialized Construction Processes in France and Architectural Flexibility</td>
<td>Leda Dimitriadi</td>
<td>385</td>
</tr>
<tr>
<td>The Dismantled War: Barracks and Industrialization of Light Construction [1914-1918]</td>
<td>Kinda Fares</td>
<td>395</td>
</tr>
<tr>
<td>The Simplification of the Frame: Window Experiments in the Work of Le Corbusier in the 1920s</td>
<td>Vanessa Fernandez</td>
<td>405</td>
</tr>
<tr>
<td>Rationalization of Systems and Materials in Construction in the Spanish Modern Movement: Fernando García Mercadal, 1921-1937, Rafael Hernando de la Cuerda</td>
<td>Rafael García García</td>
<td>413</td>
</tr>
<tr>
<td>Concrete Meccanos: Precast Constructions after the Second World War in the Netherlands</td>
<td>Rafael García García</td>
<td>421</td>
</tr>
<tr>
<td>RetCel: The Development of Floor and Roof Assemblies of Precast Concrete Cells in Colombia, 1949-1989</td>
<td>Hernando Vargas</td>
<td>431</td>
</tr>
<tr>
<td>The First ENI-SNAM Headquarters in San Donato Milanese: Some Features of Industrialization in Construction Techniques Applied to Office Buildings in the Post Second World War Period in Italy</td>
<td>Laura Greco</td>
<td>439</td>
</tr>
<tr>
<td>Flaine: Mountain City; The Building of a High Altitude Citadel, Yvan Delemontey</td>
<td>Yvan Delemontey</td>
<td>449</td>
</tr>
<tr>
<td>Architectural Expression in the 60s and the Prefabrication of Formwork, Maite Palomares Figueres, Jésica Moreno Puchalt, Veronica Llopis Pulido</td>
<td>Maité Palomares Figueres, Jésica Moreno Puchalt, Veronica Llopis Pulido</td>
<td>457</td>
</tr>
<tr>
<td>Competing Building Systems: Post-War University Architecture in the Ruhr Area, Sonja Hnilica, Markus Jager</td>
<td>Sonja Hnilica, Markus Jager</td>
<td>463</td>
</tr>
</tbody>
</table>

## Natural & Technical Risk Prevention

<table>
<thead>
<tr>
<th>Title</th>
<th>Author(s)</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not Built in a Day: Awareness of Vulnerability and Construction Techniques in Roman Times</td>
<td>Hélène Dessales</td>
<td>471</td>
</tr>
<tr>
<td>Cellars: Construction and Insulation through the Beginning of the 20th Century</td>
<td>Antonia Brauchle</td>
<td>479</td>
</tr>
<tr>
<td>Tiled Vaults in Western Sicily: Originality and Continuity of an Imported Building Technique</td>
<td>Giovanni Fatta, Tiziana Campisi, Calogero Vinci</td>
<td>487</td>
</tr>
<tr>
<td>The Use of Vaults in the Reconstruction of Pombaline Downtown Lisbon, João Caldas, Rita Lisboa</td>
<td>João Caldas, Rita Lisboa</td>
<td>495</td>
</tr>
<tr>
<td>The First Earthquake-Resistant Structures in Japan: Lessons from the Forgotten Earthquake of Ischia [1883], Nobi [1891] and San Francisco [1906], Akio Sassa</td>
<td>Akio Sassa</td>
<td>503</td>
</tr>
<tr>
<td>The Roof Frame of the Salon Carré, Guillaume Fonkenell</td>
<td>Guillaume Fonkenell</td>
<td>515</td>
</tr>
</tbody>
</table>

## Hydraulics

<table>
<thead>
<tr>
<th>Title</th>
<th>Author(s)</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Historical Aqueduct of Genoa: Materials, Techniques and History – A Way to Know</td>
<td>Anna Decri</td>
<td>525</td>
</tr>
<tr>
<td>Wooden Embankments in the Lagoon Territory of Capitanata between the 18th and 19th Centuries</td>
<td>Giuseppe Rociola</td>
<td>533</td>
</tr>
<tr>
<td>The Role of the Tsujun Irrigation Canal in the Creation of a Cultural Landscape [Shiraito Plateau, Kumamoto, Japan], Naoto Tanaka</td>
<td>Naoto Tanaka</td>
<td>549</td>
</tr>
<tr>
<td>Water Pumping Plants for Land Drainage in the Po Valley, A Case Study of The Mantua Region [1866-1940]: People, Techniques, Materials</td>
<td>Carlo Togliani</td>
<td>557</td>
</tr>
</tbody>
</table>
## Infrastructure & Public Works

- **A Cloaca Maxima in the Roman Town of Privernum, Lazio, Italy: The Project, the Plan, the Construction**, Carla Maria Amici .......... 565
- **The Roman Bridges of the Via Traiana: An Innovative Building System**, Ivan Ferrari ....... 573
- **Development and Use of Mechanized Heavy Construction Equipment in the United States**, Richard C. Ryan ........................................ 579
- **Innovation in 19th Century Vaulted Bridge Construction**, Stefan M. Holzer ................. 589
- **The Most Important Construction in Bahia’s 19th Century History: Salvador’s Mountain Retaining Wall**, Rosana Muñoz ......................... 607
- **Notes on Technological and Architectural Aspects of London Transport Power Stations and Substations, 1880-1915**, Matteo Porrino .................................. 617
- **The Highway Comes to the American City: Automobility, Urbanity and the Functioning of City Streets**, Ted Shelton ............................. 627
- **Road Construction in Greece during the Interbellum: The Makris Project**, Evangelia Chatzikonstantinou, Paschalis Samarinis, Areti Sakellaridou .......... 637
- **Historical Research for the Planning and Construction of Misumi Port**, Yuji Hoshino, Sachiko Okada, Daijiro Kitagawa ....................... 647
- **The Development of Multi-Cable-Stayed Bridges**, Eberhard Pelke, Karl-Eugen Kurzer .................................. 657
- **Technical Systems and Networks for a Modern High Altitude Settlement: The Construction of the Sanatorium Village in Sondalo [1932-1946]**, Davide Del Curto, Francesco Carlo Toso ......................... 675

**Postscript**: For a multilingual Dictionary of Construction History, André Guillerme ........................................ 685

**Author Index** ........................................ 691

**General Index** ........................................ 697

**Complete Table of Contents** .......... 717