Building Themes in Construction History: recent work by the Delaware Valley Group

JANE MORLEY

The purpose of this article is threefold: first, to introduce the work of a group of American scholars based in the Delaware River Valley region, an area extending from upper New York state to Washington, D.C.; secondly, to outline the broad themes which emerge from their work; and finally, to introduce some new perspectives on the history of building construction developed by historians of technology which recognise the complex social relations involved in what Summerson called "the building world" concerned with "the total process of getting a building up on the site" [1]. Summerson's inclusive definition of "construction history" provides a useful foundation upon which to base my discussion [2].

The Delaware Valley Group is an 'invisible college' of historians, civil engineers, architects, industrial archeologists, and historic preservationists [3]. It is based in a large number of institutions: Colgate, Cornell, Lehigh, Princeton, and the Johns Hopkins Universities; the Universities of Delaware and Pennsylvania; institutions in the Philadelphia area such as the American Philosophical Society, and in the Wilmington, Delaware area such as the Hagley Museum and Library; and at many bodies in Washington, D.C.—the National Building Museum, the National Trust for Historic Preservation, the Smithsonian Institution's National Museum of American History, the Historic American Buildings Survey (HABS) and the Historic American Engineering Record (HAER) programmes of the National Park Service, and in the Historical Division of the US Army Corps of Engineers. Several universities in the region have graduate academic programmes which take in construction history; for instance, the programme of the Hagley Museum and the Library (in association with the University of Delaware) in the History of Industrial America, Cornell's Programme in the History and Philosophy of Science and Technology, and the University of Pennsylvania's various Ph.D. programmes in the Graduate School of Fine Arts (GSFA) (including Architecture and Historic Preservation) and in the Departments of the History of Art and History and Sociology of Science. Significantly, two issues of *VIA*, Penn's GSFA student journal, have been devoted to 'Structures implicit and explicit' and 'Building architecture' [Graduate School of Fine Arts, 1973, 1985].

Seldom, however, have the members of this network formally conferred to discuss their interests and work, although there are some exceptions. The National Conference on Civil Engineering has met several times since 1970 at Princeton to discuss "History, heritage, and the humanities', and have published several volumes of proceedings [National Council on Civil Engineering, 1970; Billington, Mark & Abel, 1973; Abel & Billington, 1980]. A UNESCO organisation, the Council for Tall Buildings and Urban Habitat, is based at Lehigh University and has convened periodically since 1972; the Council's first series of volumes includes chapters on the history and construction of tall buildings. The 'Project descriptions', published in the Council's biannual volumes are useful case studies of recent construction history [Beedle, 1978–1981, 1983, 1985]. In 1976, a group of historians met under the auspices of the Carpenters' Company of Philadelphia and a volume edited by the founder of the Historic American Building Survey, Charles E. Peterson, included 'Contributions toward the history of a great industry' [Peterson, 1976]. The annual Technology Conference of the Association of Collegiate Schools of Architecture held in Washington, D.C. during the past two years has included relevant papers [Hartoonian, 1986; Peters, 1986]. Recently, architectural historian Robert Mark ran a National Endowment for the Humanities Summer Institute at Princeton on 'The technology of historic architecture', exploring the application of modern engineering analysis to the traditional historical investigation of structures. Finally, the various local chapters of the Society for Industrial Archeology (SIA) and the Association for Preservation Technology (APT), and the regionally-based Center for Canal History and Technology have newsletters and regularly scheduled activities such as lectures and site tours. The national chapters of SIA and APT also publish newsletters and journals [See, for example, Jackson, 1979; Bowie, 1985; the collection edited by Jandl, 1983; Peterson, 1987].

Few of the scholars included in this survey specifically define their work as 'construction history' and some do not see themselves as 'historians'. Nonetheless, from their seemingly diverse methods, subjects, and conclusions, themes do emerge that point to future development in the field of construction history.

Two bibliographies and three general texts by authors from the Delaware Valley region serve as introductions to the field. Eugene Ferguson's *Bibliography of the History of Technology* [1968] provides access to primary and secondary materials, and a recent bibliography by Darwin Stapleton [1986] indexes 1282 secondary works on virtually every aspect of civil engineering history since 1600. John Fitchen's *Building Construction Before Mechanization* [1986] is supplemented by Tom F. Peters' *Time is Money* [1981], published in German but now in translation for an American publisher; while Kenneth Frampton's *Modern Architecture: a critical history* [1985] deals with the architectural and aesthetic context. Together these three books provide an overview of the history of construction.

Building Themes: technology

In Summerson's definition of construction history, an important element is technology—ie knowledge, materials, tools, machines, techniques, processes—and innovation therein. Yet technology has not been a subject of major importance to most architectural historians, and in 1969 John Maass pronounced this field "skin deep and boneless" [Maass, 1969]. There is still much to learn about the making of architecture, or for that matter, any construction project. In order to understand, for example, why the 'Miesian' skyscraper was so widely built in the US after 1945, one must determine how the American context was suited to meet the material and organisational demands of such projects [Otto, 1983]. In other words, an understanding of the history of building necessarily includes its technology *and* its culture.

Several authors concerned with the history and theory of architecture have attempted to define what technology means specifically for the builder, which in these cases means the architect and structural engineer. According to structural critic Peter McCleary [1983], technology is "the discourse between societies and their natural environment in the production of the built world . . . the doing and the thinking about doing". The history of technology thus includes the movement from idea, through concept, working drawing, model, technically feasible prototype, economically feasible realisation, to use, diffusion, and transfer [McCleary, 1985]. Marco Frascari has uncovered a definition of 'construction' based on a medical analogy, as the 'therapy' prescribed in drawings and specifications to cure what Leonardo da Vinci called "the ill state of building" [Frascari, 1982]. Frascari has articulated the distinction between 'doing' and 'thinking about doing' in construction; building with the mind is *construing* and building with the hands is *construction* [Frascari, 1985]. An example of this distinction is in the documentation by Joseph Rykwert of the *construed* ideal of the primitive hut, the "point of reference for all speculations on the essentials of building" for generations of architectural theorists in many societies [Rykwert, 1981].

The 'essentials' of building have been addressed by authors from the region who have examined its basic materials, tools, and techniques. Henry Mercer [1929] and Charles Peterson [1975] have compiled artifactual and graphic materials pertaining to the history of woodworking and lumbering; Mercer founded a museum in Doylestown, Pennsylvania to display his collections of early construction artifacts, including early examples of reinforced concrete, and Peterson is currently working on the early history of concrete. A recently republished collection of papers from the Association for Presentation Technology, several of which are by regional authors, deal with a variety of building technologies, including the 'Chicago Balloon Frame', the wrought iron I-beam, the cast iron facade, architectural terra cotta, and exterior paintings [Jandl, 1983]. In his review of ancient Egyptian building, John Fitchen examined techniques such as jacking procedures, and equipment and materials such as rocker devices, scaffolding, and mortars [1978]. Robert Mark [1986] has examined the use of high-quality concrete in the construction of the dome of the Roman Pantheon and its resulting structural behaviour.

Gothic building is a rich area of research, despite the lack of historical documentation. Both Mark and Fitchen have studied Gothic building techniques. Fitchen has speculated on types of scaffolding, centering, and hoisting equipment, and masonry placement techniques used in the construction of the cathedrals [1961]. Some may disagree with Mark's use of computer and photoelastic structural-modeling methods, but his conclusions concerning the practice-based structural knowledge of the builders are valuable nonetheless: Mark believes that experience was the primary source of structural innovations such as the flying buttress and the shift from quadripartite to sexpartite vaulting. More significant may be Mark's recognition of the important role of the building culture and its system of mastered apprenticeships in the transmission of innovations from site to site, in the introduction of new methods, and in the transgenerational continuity of skills [see Mark and his various collaborators].

Building Culture

Following the definition given by Raymond Williams [4], 'culture' is used here in the anthropological sense, to indicate the work and practices of a particular group engaged in the production of a material, artistic, or intellectual product. Thus 'building culture' denotes the individuals, groups, organisations, and industries whose work, practices, and products relate to the construction of the man-made environment.

The building culture, its division of labour, and its traditions have been addressed by authors primarily interested in Renaissance Italy and the differentiation of the role of the architect from other highly skilled professionals such as engineers and practical mathematicians. The economic historian Richard Goldthwaite examined the Florentine 'building boom' of the mid-fifteenth century, and the effects of this boom on the local economy and within the culture of skilled craftsmen. His portrait of this culture (from quarries, kilns, construction yards, and techniques, to the division of labour, guild organisation, working and living conditions of the craftsmen, and the training and role of the architect) and his history of one project (the construction of the Strozzi Palace) provides an exemplary model for historians of construction. With his concern for the broader, long-term effects of the building boom, Goldthwaite shares Summerson's interest in the "tremendous ramifications upon society" of the building world [5] [Goldthwaite, 1973, 1980].

In contrast to Goldthwaite's focus on private architecture and his brief treatment of architectural style and technological innovation, Nicholas Adams, in several articles and in a book written with Simon Pepper, has examined the design and construction of civil and military architecture in fifteenth- and sixteenth-century Siena. Adams has been concerned primarily with the work of different types of 'superior artisans', such as practical mathematicians, estimators (*abacisti*) and architects, and with the sources of technological innovation in various construction projects, notably the Bruna River Dam and the Sienese fortifications [Adams, 1984, 1985]. Adams & Pepper showed that innovations in fortifications aimed to eliminate specific weaknesses observed in battle in order to make them more effective 'defence tools'; and that improvements in design closely followed innovations in military technology since structures had to accommodate, as well as defend against, new artillery and siege warfare strategies [Adams & Pepper, 1986].

Knowledge, Tradition, and Experience

A major theme in the work of Mark and Adams & Pepper is innovation and its sources in the knowledge, traditions, and practical experience of the builder. For many generations, simple constructive geometry, numerical ratios, 'rules of thumb' based on the empirical evidence of successfully functioning structures, and good judgement formed the core of the skills of the building craftsmen. The tradition of 'emulation', the effort to equal or better outstanding work, was also a major element of the craftsman's work. According to the historian of technology Brooke Hindle, this was a motivating force behind the acquisition of new methods and techniques and the invention of improved forms [Hindle, 1981]. Palladio's shift from the stonecutter's rule-of-thumb proportioning method to an organically- and musically-based aesthetic marked a change in one source of his working knowledge and skills as he made the transition from craftsman to architect [Robison, 1986b].

An analogous change occurred in the eighteenth and nineteenth centuries when the trusses and railroad bridges of recognised master builders began to fail, and these rule-of-thumb designers were gradually replaced by civil engineers who were educated in mathematics, structural mechanics, and the methods of rational engineering practice. These professionals could solve the technical problems associated with new types of structures [Jackson, 1977; Danko, 1979]. In this case, the emulation of existing bridges would not suffice in the design of economical structures which had to bear substantially increased loads: the master builder had nothing in his store of knowledge, skills, and experience to call upon as he faced such new problems.

A provocative anthropological study of builders' knowledge was done by the folklorist Henry Glassie. Glassie analysed eighteenth-century folk houses in middle Virginia in order to assess the architect/builder's 'competence', the unconscious, grammatical rules based on craft traditions which controlled design choices, and to see how this competence affected construction and how it changed with structural and design innovations [Glassie, 1975].

Builder, Architect, Engineer, or Contractor?

The changing identity of the 'builder' is another theme in the work of the Delaware Valley group. The researches of Goldthwaite and Adams have indicated that the division of labour in the building crafts was already well-defined in Renaissance Italy. Roger Moss has examined the divergence of craftsmen and architects in colonial and early republican Philadelphia, as the carpenters—like their English counterparts before them—attempted to gain more control over commissions, contracts, prices for work, and the enforcement of building regulations. With the introduction of English design books in the 1740s, the distinction between the craftsman, the master builder, and the architect was intensified [Moss, 1972, 1976]. Benjamin Henry Latrobe recognised these distinctions, especially between the master builder and the 'gentleman amateur' architect, and tried to reconcile the two by advocating the idea that the 'professional' architect should possess the best qualities of both. Latrobe himself was recognised as both an architect and engineer, seemingly able to master all of the knowledge and skills he needed to do both well [Carter, 1977–; Stapleton, 1980]. Others after Latrobe, however, were only able to do one or the other (and sometimes not too well), and the differentiation of the building culture and its increasing degrees of specialisation and professionalisation continued.

Perhaps the theme of differentiation is most forcefully addressed in the study by Sibel Dostoglu of the separation of architects from builders and the emergence of the contractor in the late nineteenth- and early twentieth-century US Architects claimed superior design expertise and professional ethics as compared with craftsmen/builders, and in so doing encouraged the replacement of the latter by general contractors, who could more effectively manage large numbers of unskilled labourers and coordinate large-scale, complex construction projects involving unfamiliar materials, building codes, and technologies. Reinforcing this trend, the master builders' craft-based skills were replaced by mechanised processes and his products by industrially-produced components [Dostoglu, 1983]. In recent years, according to McCleary, the architect's lack of understanding of structural technologies and the organisation, processes, and difficulties of construction has resulted in his functional, if not literal, removal from the construction site and his replacement by other building professionals such as structural and other consulting engineers and contractors [McCleary, 1980].

The modern builder is nowhere more clearly presented than in David Billington's work on the French engineer and contractor Robert Maillart. A scientifically-trained professional, Maillart (1872–1940) was concerned with every aspect of construction as he explored the structural and aesthetic potentials of a new material, reinforced concrete. In so doing, he brought about a union of modern structural engineering, aesthetics, and economy in his buildings and structures which Billington calls 'structural art'. Like generations of builders before him, Maillart observed the structural behaviour of his designs during construction and after completion, using them as models and learning from them in order to modify or improve future designs [Billington, 1979, 1983, 1984].

Three general but essential characteristics of successful builders have been pointed out by several historians of technology working in the Delaware Valley region. First, Eugene Ferguson has argued that master craftsmen, architects and engineers possess the ability to think and to solve problems in a non-verbal language of visual images, pictures, and objects, and then to convert these into drawings, models, specifications and structures [Ferguson, 1977]. As a measurer and estimator of costs, materials, and work required, the fifteenth-century Sienese *abaco*, Maestro Pietro, was adept at visualising mass, volume, and form [Adams, 1985]. In the eighteenth century, Latrobe's drawings indicate his highly developed ability to think visually, a faculty also possessed by the nearly illiterate engineer James Brindley [Stapleton, 1983; Hughes, 1966]. A second characteristic noted by David Billington in his studies of various structural designers and builders was that all had a strong desire to build and were highly motivated by this goal [Billington, 1983].

If a successfully completed structure is the goal, then the process of its construction may be thought of as a goal-directed system. Thomas P. Hughes has studied the builders of various technological systems and has found that specific goal-directedness, as well as visual thought and problem-solving abilities, are part of the 'seamless web' of their thought and activity. The abilities to organise, coordinate, and integrate a variety of complex technological, economic, social, and political elements into a successfully functioning system are the primary characteristics of the systems builder; he is also entrepreneurial and seeks generally in his thinking and in his activities to control and to synthesise. Consulting engineers Charles Stone and Edwin Webster are good examples of this kind of builder. Their Boston firm, Stone & Webster, was noted for the construction of dams and other structures essential to what Hughes has called "the great construction projects" of this century, electric power systems [Hughes, 1983, 1987].

Innovation: origins and effects

The builder's ability to think and to reason visually, his knowledge and experience, the craft-based tradition of emulation, and changes in these form one source of innovations in the technologies and processes of construction [6]. Adams & Pepper, Billington, Dostoglu, Hughes, and McCleary have recognised other sources, some entirely external to the building culture or construction industry. In other industries invention, research, and development activity often has its sources in a technological or institutional 'momentum', the drive to create and to produce [Hughes, 1983, 1987]. Resulting innovations have proven potentially useful to the total process of getting the building up on site. The availability of prefabricated architectural elements, and even the concepts of 'prefabrication' and 'mass-production', as sources of innovations in construction have been addressed by several regional authors, including the essays in Jandl on the invention of the balloon frame, Peterson on the iron roof and the I-beam, and Kihlstedt on the Paxton gutter. In his book on the development of American mass production, David Hounshell [1984] examines Foster Gunnison's production during the 1930s of 12 models of plywood prefabricated houses which were meant to appeal—as were the various models of General Motors automobiles—to different socio-economic levels. Walter Gropius, as Hughes has shown, was inspired by the example of mass production, and tried to emulate it in his 1926 housing project at Dessau in Germany [Hughes, 1984].

New technologies did not always mean improvements in practice. In his review of the introduction of steam power in American construction prior to 1869, Robert Vogel concluded that the industry was rather conservative in this respect because construction work required a range of power levels dispersed throughout a temporary work site—i.e. a number of different engines which might not be reusable in subsequent projects. The price of engines and other capital costs, and site conditions—dirt—also mitigated the use of steam [Vogel, 1976]. As well as these economic and environmental contingencies, bureaucratic and organisational factors could be involved. The civil works historian Martin Reuss has shown that the theoretical assertions of US Army Corps engineer Andrew A. Humphries, based on his 1861 survey of the Mississippi River Delta area, were elevated to the status of dogma in the Corps, eventually causing a general decline in its reputation as a leader in engineering science and practice [Reuss, 1985].

Even advanced developments in engineering and scientific research, however, did not necessarily affect construction practice. Bruce Seely has found that experimental, mathematically-analytical research on soil foundations and concrete slabs conducted between the world wars yielded little practical information for designers of American roadways. In fact, the major innovation originating in the Bureau of Public Roads (developing not out of its laboratories, but rather out of its negotiations with industrial and trade organisations) was in the establishment of construction codes and materials standards [Seely, 1982, 1984a, b]. Finally, some inventions required further development before they could be applied to construction: neoprene, a synthetic material invented by Du Pont, was not immediately recognised as a potential building material [Smith, 1985].

The effects of innovations are hard to predict. This is especially true of the relationship between technological innovation and architectural thinking and design, another theme emerging from the work of several authors. Rykwert has demonstrated that new materials posed problems for Lodoli in his design work because he was concerned with the appropriate representation of surfaces in accordance with scientific knowledge of their material and structural properties [Rykwert, 1982]. The structural incorporation of heating and ventilation systems into new types of buildings (often hospitals and prisons) was gradually resolved by British architects after the middle of the nineteenth century, and contributed to new architectural conceptions of buildings as machines or biological systems, and their components as tools or membranes [Breugmann, 1978]. Some architects who chose to build in new materials, for example, William K. Price of Philadelphia, developed both technical and aesthetic theories: around the turn of the century, Price sought an 'ahistorical and expressive vocabulary" for reinforced concrete in commercial and residential structures [Thomas, 1975; 1985] [7]. From 1904–1933, architects in the German *Bund für Heimatschutz* called for the integration of new building materials and types into the landscape and the preservation of the older, traditional structures [Otto, 1983]. Recently, the Philadelphia architect and planner Denise Scott Brown pointed out that the 'American place' has been, and continues to be, invented through new 'innovations' and 'reinventions' which refer to older, traditional forms [Scott Brown, 1986]. In contrast the architect of the English Law Courts, George Edmund Street, was 'ambiguous' about the use of machinery on the construction site as he maintained his aesthetic position as a 'modern medievalist' [Brownlee, 1984]. For other architects, however, technology has been a tool to realise a form which could not otherwise have been built. To Louis Kahn, technology—*techne*—was a kind of reflection-in-action, the mediation between the architectural idea and the reality of the built form, and his structural modifications of the Roman vaults for the Kimball Art Museum in Forth Worth, Texas produced the quality of interior light that he desired [McCleary, 1986; Meyers, 1979].

For some twentieth-century architectural designers (including engineers), technology has been the defining feature of their work. Sir Owen Williams was especially noted for his "repertoire of technical solutions". Yet, not all of what appear to be are in reality necessary technical features of his designs. The external row of reinforced concrete roof frames in his 1934 Empire Swimming Pool at Wembley, England serve only as *visual* counterbalances in the structure, and thus help to fulfil his aesthetic preferences rather than technical needs [Frampton, 1970; Mark & Perlmutter, 1972]. Dostoglu [1984] has argued that Williams, along with Ove Arup and Frank Newby, falls into the 'engineering tradition' of twentieth-century designers, one of four traditions which also include the 'industrialized tradition', 'British experimentalism', and 'High Tech'.

Conclusion: the social construction of building

As practised in the Delaware Valley region, construction history has many themes in common with the histories of architecture and technology, largely because the authors were addressing those fields. These themes include: a concern with technology and how it is defined by the various groups involved in practice; basic materials, tools, and techniques; the role of knowledge, skills, traditions, and experience; the culture of practice and its historically changing division of labour, and finally, the sources of innovation within the culture and outside of it, and the effects of these innovations generally on thought and practice. Further questions and themes remain that construction historians, by virtue of their position between two communities of historical discourse, are perhaps uniquely suited to address. Who and what is responsible for the historically changing definitions of the 'builder' and his assigned responsibilities? How have these responsibilities changed, and in turn shaped the nature of his thought and activity? Why have builders chosen or rejected particular technologies and methods in order to construct their projects? How did builders cope with unanticipated technical or organisational difficulties during construction? What were the available alternative choices of labour or materials? What were the political, economic, social, and personal factors presenting constraints or options, influencing their choices, and thus affecting the completion of their projects? With the help of a number of regional authors, I have tried in this review to point to various ideological, political, economic, institutional, and social factors which have influenced the choice of technologies for, and the completion of, the architectural and engineering projects which create the man-made environment. We may call these factors the social forces that shape construction: they remind us that the built world is both *technically* and *socially* constructed [8] [Hughes with Bijker & Pinch, 1987]. Construction history, however, involves more than this; for one Delaware Valley region author, it is the stuff of poetry (Morgan, 1986).

Correspondence: Jane Morley, Department of History and Sociology of Science, School of Arts and Sciences, University of Pennsylvania, Philadelphia, Pennsylvania 19104-6310, USA.

Notes

[1] The preparation of this essay was aided by a dissertation fellowship from the Program for Assessing and Revitalizing the Social Sciences, a program at the University of Pennsylvania funded by a grant from the Andrew W. Mellon Foundation. I am also indebted to the technical assistance of Dr Dennis A. Yao.
[2] John Summerson, "What is the History of Construction?, *Construction History*, 1 (1985), p. 1.
[3] See D. Crane, *Invisible Colleges* (Chicago, 1972).
[4] Raymond Williams, *Keywords: A Vocabulary of Culture and Society* (rev. edn. London, 1983), pp. 87–93.
[5] Summerson, p. 1.
[6] See J. Staudenmaier, *Technology's Storytellers: Reweaving the Human Fabric* (Cambridge, Mass., 1985), pp. 50–55.
[7] The 1985 article by Thomas is perhaps the best short case study of a construction project yet produced in the Delaware Valley region.
[8] See D. Mackenzie and J. Wajcman, eds., *The Social Shaping of Technology* (Milton Keynes, 1985).

Bibliography

John F. Abel and David P. Billington, eds. (1980), *Civil Engineering: History, Heritage and the Humanities, III; Perspectives on the History of Reinforced Concrete in the United States, 1904–1941: Conference Papers from the Solomon Cady Hollister Colloquium* (Conference held at Princeton University, 2 June 1980) (Department of Civil Engineering, Princeton University)

Nicholas Adams (1984), 'Architecture for Fish: The Sienese Dam on the Bruna River—Structures and Designs, 1468–ca. 1530', *Technology and Culture*, 25, pp. 768–797

Nicholas Adams (1985), 'The Life and Times of Pietro dell'Abaco, A Renaissance Estimator from Siena (active 1457–1486), *Zeitschrift für Kunstgeschichte*, 48, pp. 384–395

Nicholas Adams and Simon Pepper (1986), *Firearms and Fortifications: Military Architecture and Siege Warfare in Sixteenth Century Siena* (Chicago)

Association Villard de Honnecourt for the Interdisciplinary Study of Medieval Technology, Science and Art (1986) *AVISTA Forum*, 1 no. 1 (Haverford College, Haverford, Penn.)

Lynn S. Beedle, ed. (1978–81), *Planning and Design of Tall Buildings, A Monograph* (Proceedings of the International Conference on Planning and Design of Tall Buildings, 21–26 August 1972, Lehigh University, Bethlehem, Penn.), (5 vols, New York, American Society of Civil Engineers)

Lynne S. Beedle (1983), *Developments in Tall Buildings—1983, An Update of Monograph on Planning and Design of Tall Buildings* (Stroudsburg, Penn., Council on Tall Buildings and Urban Habitat, UNESCO)

Lynne S. Beedle (1985), *Advances in Tall Buildings, An Update of Monograph on Planning and Design of Tall Buildings* (New York, Council on Tall Buildings and Urban Habitat, UNESCO)

David Billington (1973), 'Art in Engineering—the Need for a New Criticism', *Engineering Issues*, 99, pp. 499–511. [Revised and reprinted in James H. Schaub and

Sheila K. Dickinson, eds. *Engineering and the Humanities* (New York, 1982) pp. 176–189]
David Billington (1979), *Robert Maillart's Bridges: The Art of Engineering* (Princeton, New Jersey)
David Billington (1983), *The Tower and the Bridge: The New Art of Structural Engineering* (New York)
David Billington (1984), 'Building Bridges: Perspectives on Recent Engineering', in *Bridge to the Future, A Centennial Celebration of the Brooklyn Bridge* (New York, New York Academy of Sciences), pp. 309–324.
David Billington and Robert Mark (1984), 'The Cathedral and the Bridge: Structure and Symbol', *Technology and Culture*, 25, pp. 37–52. [See also the critique by Carl Condit and the authors' response in the same volume]
David Billington, Robert Mark and John F. Abel, eds. (1973), *Civil Engineering: History, Heritage and the Humanities, II; Background Papers; The Maillart Papers: Commemorating the Hundredth Anniversary of the Birth of Robert Maillart* (Conference held at Princeton University, 4–6 October 1972) (2 vols, Princeton, New Jersey)
John R. Bowie (1985), 'Documentation of America's Industrial Heritage: The Historic American Engineering record', *APT*, 17 no. 1, pp. 47–56
David B. Brownlee (1984), *The Law Courts: The Architecture of George Edmund Street* (Cambridge, Mass.)
Robert Bruegmann (1978), 'Central Heating and Forced Ventilation: Origins and Effects on Architectural Design', *Journal of the Society of Architectural Historians*, 37 no. 3, pp. 143–160
Edward C. Carter, II, ed. (1977–), *The Papers of Benjamin Henry Latrobe* (in progress, 7 vols, New Haven, Conn., Maryland Historical Society) [See also Stapleton, 1980, below]
Center for Canal History and Technology (1982–), *Proceedings of the Canal History and Technology Symposium*, 1– (Easton, Penn., Center for Canal History and Technology)
George M. Danko (1979) 'The Evolution of the Simple Truss Bridge, 1790–1850: From Empiricism to Scientific Construction' (unpublished Ph.D. thesis, University of Pennsylvania)
Harold Dorn (1970) 'Art of Building and the Science of Mechanics' (unpublished Ph.D. thesis, Princeton University)
Sibel Dostoglu (1983), 'Lincoln Cathedral versus the Bicycle Shed', *Journal of Architectural Education*, 36 no. 4, pp. 10–15
Sibel Dostoglu (1984), 'Technological Discourse', *International Architect/U.I.A.*, 5, pp. 47–53
Eugene Ferguson (1968), *Bibliography of the History of Technology* (Cambridge, Mass., Society for the History of Technology)
Eugene Ferguson (1976), 'An Historical Sketch of Central Heating: 1800–1860', in Charles E. Peterson, ed. *Building Early America* (Radnor, Penn.) pp. 165–185
Eugene Ferguson (1977), 'The Mind's Eye: Nonverbal Thought in Technology', *Science*, 197 no. 4306, pp. 827–836
John Fitchen (1961), *The Construction of Gothic Cathedrals: A Study of Medieval Vault Erection* (Oxford)
John Fitchen (1968), *The Dutch New World Barn: A Study of Its Characteristics, Its Structural System, and Its Probable Erectional Procedures* (Syracuse, N.Y.)

John Fitchen (1978), 'Building Cheops Pyramid', *Journal of the Society of Architectural Historians*, 37, pp. 3–12
John Fitchen (1986), *Building Construction before Mechanization* (Cambridge, Mass.)
Kenneth Frampton (1970), 'Sir Owen Williams, 1890–1969: The Engineer as Architect', in *Civil Engineering: History, Heritage, and the Humanities I; Background Papers* (Princeton, New Jersey), pp. 21–58
Kenneth Frampton (1985), *Modern Architecture: A Critical History* (London)
Marco Frascari (1982), 'Professional Use of Signs in Architecture', *Journal of Architectural Education*, 36, pp. 16–23
Marco Frascari (1985), 'The Tell-the-Tale Detail', in *VIA VII: Building Architecture* (Cambridge, Mass.), pp. 23–38
Henry Glassie (1975), *Folk Housing in Middle Virginia: A Structural Analysis of Historic Artifacts* (Knoxville, Tennessee)
Richard A. Goldthwaite (1973), 'The Building of the Strozzi Palace: The Construction Industry in Renaissance Florence', *Studies in Medieval and Renaissance History*, 10, pp. 99–194
Richard A. Goldthwaite (1980), *The Building of Renaissance Florence: An Economic and Social History* (Baltimore)
Graduate School of Fine Arts, University of Pennsylvania (1973), *VIA II: Structures Implicit and Explicit* (Cambridge, Mass.)
Graduate School of Fine Arts, University of Pennsylvania (1985), *VIA VII: The Building of Architecture* (Cambridge, Mass.)
E. A. Gutkind (1964–1972), *International History of City Development* (8 vols, New York)
Gevork Hartoonian (1986), 'Poetics of Technology and the New Objectivity', *Journal of Architectural Education*, 40 no. 1, pp. 14–19
Brooke Hindle (1981), *Emulation and Invention* (New York and London)
Historic American Buildings Survey (HABS)/Historic American Engineering Record (HAER) (1983), *Historic America: Buildings, Structures, and Sites* (Washington D.C., Library of Congress)
HABS/HAER (1985), *Historic American Engineering Record Checklist: 1969–1985* (Washington, D.C.: HABS/HAER, National Park Service, U.S. Dept. of the Interior)
David A. Hounshell (1984), *From the American System to Mass Production, 1800–1932: The Development of Manufacturing Technology in the United States* (Baltimore)
Thomas P. Hughes, ed. (1966), *Selections from "Lives of the Engineers with an Account of their Principle Works" by Samuel Smiles* (Cambridge, Mass.)
Thomas P. Hughes (1983), *Networks of Power: Electrification in Western Society, 1880–1930* (Baltimore)
Thomas P. Hughes (1984), 'Gropius, Machine Design, and Mass Production', *Jarbuch 1983/84, Wissenschaftskolleg zu Berlin* (Berlin)
Thomas P. Hughes (1986), 'The Seamless Web: Technology, Science, Etcetera, Etcetera', *Social Studies of Science*, 16 (1986), pp. 281–292
Thomas P. Hughes (1987) 'The Evolution of Large Technological Systems', in Wiebe Bijker, Trevor Pinch, and Thomas P. Hughes, eds. *The Social Construction of Technology* (Cambridge, Mass.)
Thomas P. Hughes, Wiebe Bijker and Trevor Pinch (1987), *The Social Construction of Technology* (Cambridge, Mass.)

Donald Jackson (1977), 'Railroad Truss Bridges and the Rise of the Civil Engineer, *Civil Engineering*, 47 no. 10, pp. 97–101
Donald Jackson (1979), 'John S. Eastwood and the Mountain Dell Dam', *IA: The Journal of the Society for Industrial Archeology*, 5, pp. 33–48
H. Ward Jandl, ed. (1983), *The Technology of Historic American Buildings: Studies of the Materials, Craft Processes, and the Mechanization of Building Construction* (Washington, D.C., Foundation for Preservation Technology for the Association for Preservation Technology)
Folke T. Kihlstedt (1984), 'The Crystal Palace', *Scientific American*, 251 no. 4, pp. 132–143
Carter Litchfield et al. (1984), *The Bethlehem Oil Mill, 1745-1934: German Technology in Early Pennsylvania* (Kemblesville, Penn.)
John Maass (1969), 'Where Architectural Historians Fear to Tread', *Journal of the Society of Architectural Historians*, 28, pp. 3–8
Robert Mark (1977), 'Robert Willis, Viollet-le-Duc and the Structural Approach to Gothic Architecture', *Architectura*, 7 no. 1, pp. 52–64
Robert Mark (1982), *Experiments in Gothic Structure* (Cambridge, Mass.)
Robert Mark (1982), 'Modeling Architectural Structure: Experimental Mechanics in Historiography and Criticism', *Experimental Mechanics*, 22 no. 10, pp. 361–371
Robert Mark (1983), 'Construction: Engineering', in J. Strayer, ed. *Dictionary of the Middle Ages* (New York)
Robert Mark and William W. Clark (1984), 'The First Flying Buttresses: A New Reconstruction of the Nave of Notre-Dame de Paris', *Art Bulletin*, 66 no. 1, pp. 47–65
Robert Mark and William W. Clark (1984), 'Gothic Structural Experimentation', *Scientific American*, 251, pp. 176–185
Robert Mark and Harold Dorn (1981), 'The Architecture of Christopher Wren', *Scientific American*, 245 no. 1, pp. 160–175
Robert Mark and Paul Hutchinson (1986), 'On the Structure of the Roman Pantheon', *Art Bulletin*, 68 no. 1, pp. 24–34
Robert Mark and Roy Perlmutter (1972), 'Engineer's Aesthetic vs. Architecture: The Design and Performance of the Empire Pool at Wembley', *Journal of the Society of Architectural Historians*, 31, pp. 56–60
Robert Mark and Lon R. Shelby (1979), 'Late Gothic Structural Design in the "Instructions" of Lorenz Lechler', *Architectura*, 9 no. 2, pp. 113–131
Robert Mark and William Taylor (1982), 'The Technology of Transition: Sexpartite to Quadripartite Vaulting in High Gothic Architecture', *Art Bulletin*, 64, pp. 579–587
Peter McCleary (1980), 'Structure and Intuition', *AIA Journal*, 69 no. 12, pp. 56–59 and 119
Peter McCleary (1983), 'An Interpretation of Technology', *Journal of Architectural Education*, 37 no. 2, pp. 2–4
Peter McCleary (1985), 'History of Technology', in James C. Snyder, ed. *Architectural Research* (New York), pp. 81–94
Peter McCleary (1987), 'The Kimball Art Museum—Architect Louis I. Kahn: A Technological Critique', *Design Book Review*, 11 (Winter 1987), pp. 48–51
Henry C. Mercer (1929; rep. 1975), *Ancient Carpenters' Tools: Together with Lumbermans', Joiners' and Cabinet Makers' Tools in Use in the Eighteenth Century* (Doylestown, Penn.: Bucks County Historical Society)

Marshall Meyers (1979), 'Masters of Light: Louis I. Kahn', *AIA Journal*, 68 no. 11, pp. 60–62
Robert Morgan (1986), 'Sigodlin', *The Atlantic*, 258 no. 6, p. 80
Roger W. Moss (1972), 'Master Builders: A History of the Colonial Philadelphia Buildings Trades' (unpublished Ph.D. thesis, University of Delaware)
Roger W. Moss (1976), 'The Origins of the Carpenters' Company of Philadelphia', in Charles E. Peterson, ed. *Building Early America: Contributions toward the History of a Great Industry* (Radnor, Penn.), pp. 35–53
National Conference on Civil Engineering (1970), *Civil Engineering: History, Heritage and the Humanities, I: Background Papers; Selected Papers* (Conference held at Princeton University, 14-16 October 1970) (3 vols, Princeton, New Jersey)
Christian F. Otto (1983), 'American Skyscrapers and Weimar Modern: Transactions between Fact and Ideas', in *The Muses Flee Hitler: Cultural Transfer and Adaptation, 1930–1945* (Washington, D.C., Smithsonian Institution), pp. 151–168
Christian F. Otto (1983), 'Modern Environment and Historical Continuity: The Heimatschutz Discourse in Germany', *Art Journal*, 43, pp. 148–157
Tom F. Peters (1981) *The Development of Long-Span Bridge-Building* (3rd edn., Zurich)
Tom F. Peters (1981), *Time is Money—Die Entwicklung des modernen Bauwesens* (Stuttgart)
Tom F. Peters (1986), 'Report of an Ongoing Experiment: Case Studies in Construction as Examples of Theoretical and Historical Approaches to Teaching Technology in Architecture', *Journal of Architectural Education*, 39 no. 4, pp. 11–21
Charles E. Peterson (1968), 'Iron in Early American Roofs', *Smithsonian Journal of History*, 3 no. 3, pp. 41–76
Charles E. Peterson (1969), 'The Technology of Early American Building', *APT*, I no. 1, pp. 3–17
Charles E. Peterson (1975), 'Early Lumbering: A Pictorial Essay', in Brooke Hindle, ed. *America's Wooden Age: Aspects of its Early Technology* (Tarrytown, New York), pp. 63–84
Charles E. Peterson, ed. (1976), *Building Early America: Contributions Toward the History of a Great Industry* (Radnor, Penn.)
Charles E. Peterson (1983), 'Inventing the Iron Beam: Richard Turner, Cooper & Hewitt and Others', in H. Ward Jandl, ed. *The Technology of Historic American Buildings* (Washington D.C.), pp. 63–96 [Originally published in 1980 in *APT*, 12 no. 4, pp. 3–28]
Martin Reuss (1985), 'Andrew A. Humphries and the Development of Hydraulic Engineering: Politics and Technology in the Army Corps of Engineers, 1850–1950', *Technology and Culture*, 26 no. 1, pp. 1–33
Elwin C. Robison (1985), 'Guarinno Guarini's Church of San Lorenzo in Turin' (unpublished Ph.D. thesis, Cornell University)
Elwin C. Robison (1986a), 'Structural Calculations and American High-Rise Development from the Chicago Fire to the Development of High-Speed Computers' (unpublished conference paper, 1986)
Elwin C. Robison (1986b), 'Palladio and Traditional Design Techniques' (unpublished conference paper, 1986)
Joseph Rykwert (1972; 1981), *On Adam's House in Paradise* (Cambridge, Mass.)
Joseph Rykwert (1982), *The Necessity of Artifice* (New York)
Denise Scott Brown (1986), 'Invention and Tradition in the Making of an American

Place', in *Precedent and Invention. The Harvard Architecture Review 5* (New York), pp. 162–171
Bruce E. Seely (1982), 'Highway Engineers as Policy Makers: The Bureau of Public Roads, 1893–1944' (unpublished Ph.D. thesis, University of Delaware)
Bruce E. Seely (1984), 'The Scientific Mystique in Engineering: Highways Research at the Bureau of Public Roads, 1918–1940', *Technology and Culture*, 25, pp. 798–831
Bruce E. Seely (1984), 'Engineers and Government-Business Cooperation: Highway Standards and the Bureau of Public Roads', *Business History Review*, 58, pp. 51–77
John K. Smith (1985), 'The Ten Year Invention: Neoprene and Du Pont Research, 1930–1939', *Technology and Culture*, 26 no. 1, pp. 34–55
Darwin Stapleton, ed. (1980), *The Engineering Drawings of Benjamin Henry Latrobe* (New Haven, Conn., Maryland Historical Society)
Darwin Stapleton (1986), *The History of Civil Engineering Since 1600: An Annotated Bibliography* (Bibliographies in the History of Science and Technology, New York)
George E. Thomas (1975), 'William L. Price (1861–1916): Builder of Men and Buildings' (unpublished Ph.D. thesis, University of Pennsylvania)
George E. Thomas (1984), 'A House Built on Sand: The Construction of Atlantic City's Traymore Hotel', in *VIA VII: Building Architecture* (Cambridge, Mass.)
Robert M. Vogel (1971), *Roebling's Delaware & Hudson Canal Aqueducts* (Washington, D.C., Smithsonian Institution)
Robert M. Vogel (1973), *A Report of the Mohawk-Hudson Area Survey: A Selective Recording Survey of the Industrial Archeology of the Mohawk and Hudson River Valleys in the Vicinity of Troy, New York, June–September 1969* (Washington, D.C., Smithsonian Institution)
Robert M. Vogel (1976), 'Building in the Age of Steam', in Charles E. Peterson, ed. *Building Early America: Contributions toward the History of a Great Industry* (Radnor, Penn.), pp. 119–134
Robert M. Vogel (1983), *Building Brooklyn Bridge: The Design and Construction 1867–1883* (Washington, D.C., Smithsonian Institution)
Robert M. Vogel (1984), 'Designing the Brooklyn Bridge', in *Bridge to the Future, A Centennial Celebration of the Brooklyn Bridge* (New York, New York Academy of Sciences), pp. 3–39

The Rise of the Metal Window during the Early Industrial Period in Britain, c.1750–1830

H. J. LOUW

By comparison with fields like the textile industry, the building industry's immediate material benefits from the Industrial Revolution were not extensive since relatively few manufacturing processes, machines or materials were developed specifically to solve architectural problems during the eighteenth and early nineteenth centuries. However, like most other activities architecture could not escape the great tide of invention that swept through countries such as Britain and France from about the middle of the eighteenth century. The greatest impact undoubtedly came by the increased availability of metal, especially iron, for engineering, building and decorative purposes. The effect of this development on structural design is well recorded in regard to utilitarian structures such as bridges and industrial buildings, but other aspects of architecture have received little attention [1]. This study aims to investigate the influence of these technological advances on one such area: window design.

The metal window has long been recognised by scholars as a 'leitmotif of industrialised building', and as such it has been accepted as a major factor in the development of the 'Modern Movement' in architecture. Since it is also one of the few elements constituting a modern building whose lineage can be traced back uninterruptedly to the period of the first major technical transformations from which twentieth century architecture emerged, it is indeed surprising that no one has attempted yet to write its history. This paper deals with the early and least known phase of the development—the period before, as Giedion put it, 'mechanisation took command'—leaving the latter part of the story for another occasion. The study is limited to Britain, the birthplace of the Industrial Revolution, and hence the natural starting point for a history of the machine-made metal window.

The Pre-industrial Era

It was in the sixteenth century, when glazed windows with openable sections were adopted on a large scale in northern Europe, that metal first came to be employed as an integral part of window frames. These opening sections or *casements* had wrought iron frames each of which held a lattice of lead with small diamond-shaped glass quarries. This development seems to have been confined largely to England; on the Continent, wood, which was cheaper and allowed much more weathertightness, was the preferred material for windows of that kind. This is not the place to explore the reasons why England should have taken a separate course from the rest of Europe. Suffice it to say that the English persisted in their use of leaded iron casements for the next two centuries despite obvious defects and the criticism of foreign observers [2]. As late as