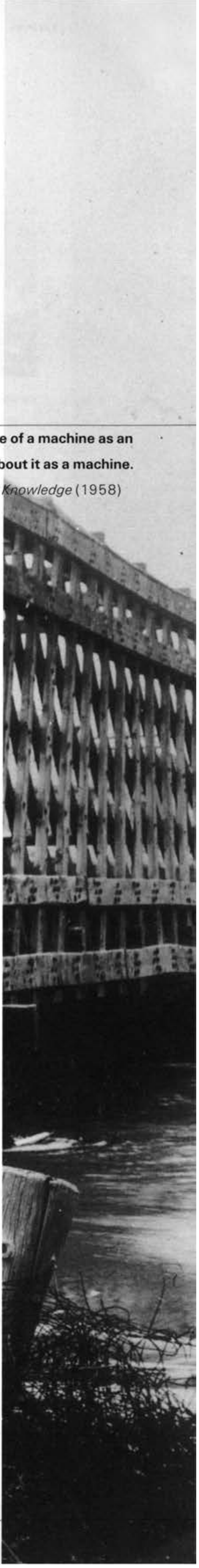
BUILDING MYTHS:

THE 'EVOLUTION' FROM WOOD TO IRON IN THE CONSTRUCTION OF BRIDGES AND NATIONS

Jordan River Bridge, Salt Lake City, Utah

Gregory K. Dreicer

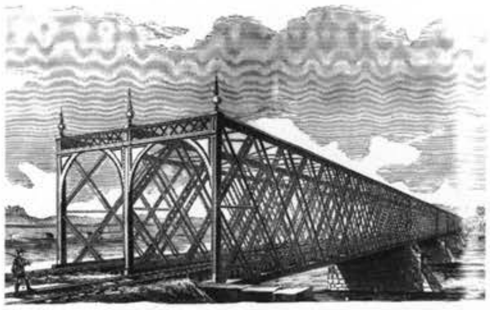
> **The complete knowledge of a machine as an object tells us nothing about it as a machine.**
> Michael Polanyi, *Personal Knowledge* (1958)



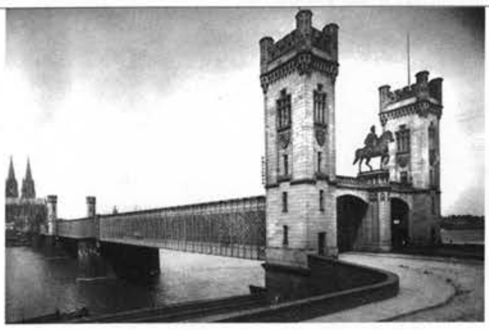
Engineers and historians have constructed our understandings of structural design out of 'great divides': practice versus theory, wood versus iron, unsophisticated versus advanced, Europe versus the United States. 'Practice,' 'wooden,' 'unsophisticated,' and 'American' represented one side of a mythical divide that helped propel personal, institutional, and industrial competition in the nineteenth century. This became historical explanation in the twentieth. With a better understanding of the divides, architects and engineers will have a sharper picture of the forces that continue to drive design and the justifications made for design decisions.

We need a bridge, not a divide, to understand a history that includes the full gamut of cultural and physical forces, including nationalist fervor, creative genius, capitalist greed, a yearning for professional prestige, and tension and compression. Examining the effect of these forces on bridge design will reveal much about the origins of the frameworks that undergird our world. It will also give us a better idea of what a culture is and isn't: what it means for a thing or a person, or a group of things or a group of people, to be labeled 'theoretical,' 'iron,' 'sophisticated,' and 'European.'

Using a nineteenth-century structure, the lattice bridge, as a touchstone, I will examine three interlocking myths held dear by historians of building: evolutionary theory as explanatory device, the hierarchy of wood and iron, and the influences of nations on the development of structure.



Connecticut River Bridge, Springfield, Massachusetts, Charles Hilton (1874)



Cologne Bridge, Cologne, Germany Hermann Lohse (1855 – 58)

If an engineer builds a structure which breaks, that is a mischief, but one of a limited and isolated kind, and the accident itself forces him to avoid a repetition of the blunder. But an engineer who from deficiency of scientific knowledge builds structures which don't break down, but which stand, and in which the material is clumsily wasted, commits blunders of a most insidious kind.

William Cawthorne Unwin, Professor of Hydraulic and Mechanical Engineering, Royal Indian Civil Engineering College (c. 1889)

UNNATURAL SELECTION

Construction has rarely been considered culturally significant, so most records of nineteenth and twentieth century building have been tossed into the garbage. Engineers' histories typically consist of anecdotes leavened by a belief in natural selection – a belief adopted by the professional historians who read their writings. Today, to the extent that there is *any* prevailing theory of development of civil engineering structures such as bridges, it is evolutionary. The term 'evolution' often surfaces in the titles and introductions that establish the theoretical foundations of these histories.[2] While evolution appears merely to create an orderly history out of disorderly reality, it is more than an ordering device. It is like a great work of science (really, technology) fiction, within which structures and building processes are causally connected from the beginning to the end of time.

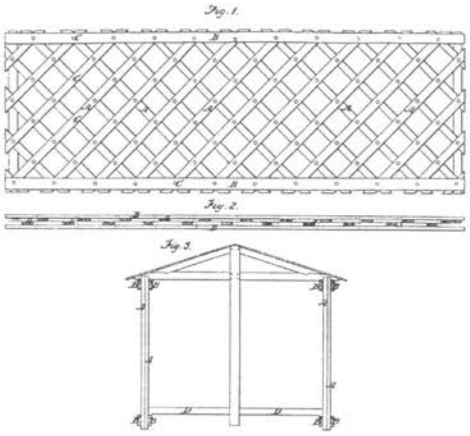
Engineers used evolutionary theory to defend practices, hide uncertainties, and legitimize mistakes. For example, Theodore Cooper (1839 – 1919), an engineer known as the author of standard bridge specifications, and the designer of a bridge that collapsed catastrophically during construction, believed that:

> *The intelligent investigator does not decide upon the merits of any developed system by the failures which are necessary steps in its development. Without variations and failures there would be no evolution or survival of the fittest.*[3]

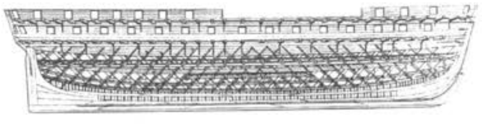
Herbert Spencer's widely read philosophy and his phrase 'survival of the fittest,' so meaningful to late nineteenth century industrialists, seemed to allow engineers to justify the death of train passengers in bridge collapses, if that's what it took for the 'fittest' bridge system to 'evolve.'[4] A bridge type must be fit to survive, but evolution-minded engineers rarely noted that the meaning of 'fit' can vary enormously according to context and whom you ask. It may depend on the price of labor, the width of a river, or the decision of a king.[5]

Historians of technology have produced a body of work that supports nineteenth century engineers' self image as agents of evolutionary progress. Swiss engineering professor Jules Gaudard began his 1892 text on bridge construction by stating, 'Under the hand of man, things

Worm fence (depicted 1787)



E.G.: Lattice bridge, patent drawing, Ithiel Town (1820)



Diagonal bracing of ship frames, Robert Seppings (1806 – 1811)

seem to come to life, join with his aspirations, and, like him, struggle for existence.' When writing his 1979 dissertation on the 'evolution of truss bridge design,' George Danko stated, 'The early railroad systems were, in fact, experimental laboratories in which the simple truss was allowed to develop. Different models were tried and the most successful design survived.' Engineer Henry Petroski recently claimed that 'with the increasing production and application of iron in the nineteenth century, trusses naturally evolved into a plethora of types and styles employing the new material.' To building historians, Darwinism was a Siren, and they headed toward the rocks.[6]

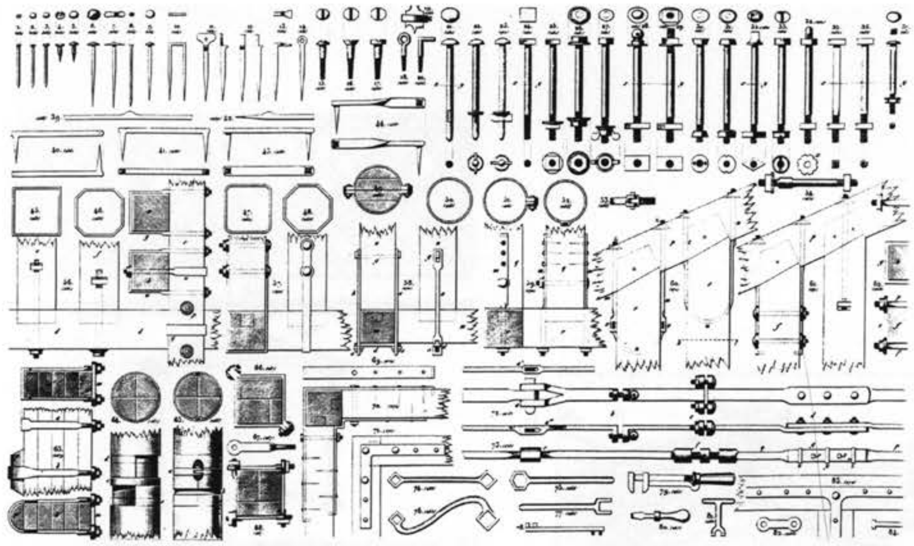
Natural history cannot explain the networks of people, ideas, and artifacts behind an engineering structure. The history of the lattice bridge reveals a decidedly unnatural creation.[7]

An 'improvement in the construction of wood and iron bridges' was registered with the U.S. Patent Office in 1820 by Ithiel Town (1784–1844), an architect, bridge engineer, and builder. His invention, consisting of frameworks of diagonally intersecting planks, became a prototype for the long-span truss systems developed during the nineteenth century. Over waterways and valleys, from Alabama to Bavaria to Russia, builders erected what came to be known as 'American bridges.' Compared to existing frame systems, the lattice possessed a uniformity and rectilinear clarity that made it one of the earliest engineering pinups of the railway age.

The lattice bridge, designed for quantity production, became the Model T of industrial structures. It inspired engineers to create the wood and metal truss frameworks that became fundamental engineering structures. Theorists consequently developed standard methods of analysis.[8]

Natura non facit saltum ('nature makes no jumps') was a favorite Latin saw of Charles Darwin.[9] Gradual bit-by-bit emergence is central to his theory. Does it hold for building? Was the lattice bridge just a small step? It appeared to be a long jump to most observers. It meant a switch from massive stone arch construction as well as wood and iron translations. It challenged fundamental beliefs about building materials, redundancy, durability, safety, appearance, and time. It was apparently conceived by combining structures, ideas, and processes that could be found in a fence, a ship frame, or a garden trellis. Yet the amalgamation was startlingly novel in both conception and physical form.

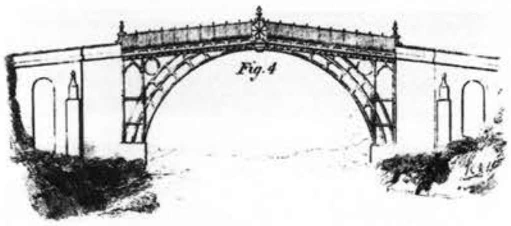
When Darwin wrote, 'almost every part of every organic being is so beautifully related to its complex conditions of life that it seems as improbable that any part should have been suddenly produced perfect, as that a complex machine should have been invented by man in a perfect state,' he implied what many now believe about technological objects – that they become perfected through evolution.[10] Darwin's analogy points to the decidedly technological character of evolution, whose mechanical processes of variation and selection are often noted. Evolution proceeds autonomously: nature's slow-going assembly lines deliver species.[11] In clarifying a natural process, evolution made biology 'mechanical' and thereby scientific. When the analogy was then re-applied to its source – human activity – it made technological development mystical: individual designers had reasons for their actions, but as a group they became agents of autonomous progress.



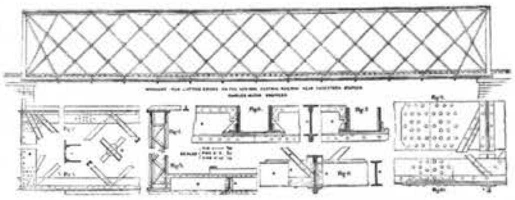
Iron hardware for 'wooden' structures (1837)

When we no longer look at an organic being as a savage looks at a ship, as something wholly beyond his comprehension; when we regard every production of nature as one which has had a long history; when we contemplate every complex structure and instinct as the summing up of many contrivances, each useful to the possessor, in the same way as any great mechanical invention is the summing up of the labour, the experience, the reason, and even the blunders of numerous workmen; when we thus view each organic being, how far more interesting – I speak from experience – does the study of natural history become!

Charles Darwin, *Origin of the Species* (1859)



Iron bridge, Coalbrookdale, England
Abraham Darby III, iron founder (1779)



Bridge near Canestota Station, New York, Charles Hilton (1864)

Sigfried Giedion observed fifty years ago that 'evolution is now used interchangeably with progress,' and this is still true.[12] Bridges and buildings are always becoming more sophisticated; steel is superior to iron, which is superior to wood. The social Darwinist conception of evolution presupposes that the evolving object or system is heading toward a goal of improvement.[13] It reinforces popular belief in the autonomy and inevitability of technological development – a history in which things keep getting better.

But there is no ideal building or bridge design; there are always many choices. Designers must confront a technological (also known as a cultural, physical, economic, political) environment that they interpret and manipulate to make an invention succeed. For an architect, it is a matter, as Le Corbusier pointed out, of first formulating the question.[14]

THE NATURELESSNESS OF MATERIALS

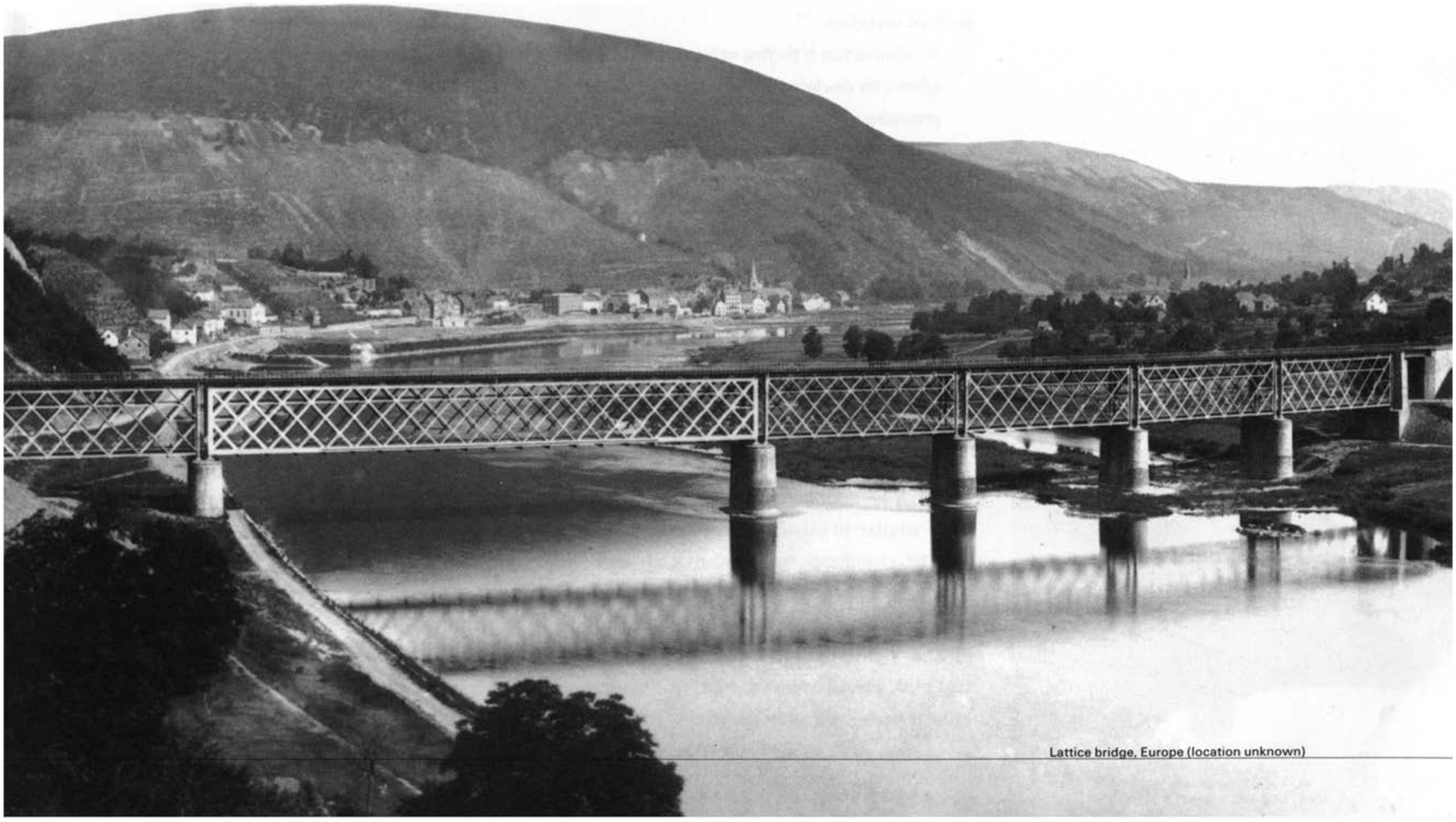
In order to explain bridge development, historians have classified bridges by appearance: by types of forces (tension or compression); by designer (hero-genius); by location; by size (the bigger the better); by chronology (in which 'firsts' are all-important); and by material. The ideas behind these classifications are rarely examined. Size and scale are only two of many measures of significance, and chronology may reveal little about kinship. Grouping by material, a practice taken from engineering textbooks, may result in skewed conclusions: one finds pronouncements such as, 'the iron truss came soon after the iron arch.'[15] An examination of design conceptions rather than material manufacture reveals that the relationship between an iron arch bridge and an iron truss bridge was not direct. Before chaining systems together, one must understand the reasons behind their emergence.

The fact that a bridge was 100 percent iron is not necessarily significant for the history of structures. In fact, the first 'all-iron' bridges may be considered the least interesting, because they were imitations of existing structures. The so-called first (cast-)iron bridge, built in Coalbrookdale, England, around 1779, was based on stone construction, with details that duplicated wood connection technology. Yet this 'first' has been trumpeted as a remarkable British achievement and major advance in bridge building for two hundred years. While it may have served as an inspiration, this was an advance in some respects similar to the substitution of metal for wood in doorknob manufacture. Coalbrookdale is a monument to the belief that iron made civil engineering modern.[16]

But here is a shock: a critical selling point of the lattice bridge was that no iron was used. Although Town stated that the whole bridge could be built in iron, he deliberately invented and built bridges that included no iron. It was made of uniform size parts: plank and wooden pegs. Iron was considered a disadvantage rather

The first crude stone missile begat the spear, which begat the arrow and then the bolt, the bullet, and so on to Star Wars. Human volition seems to have less to do with this development than do the potentialities inherent in the objects themselves.

Mihaly Csikszentmihalyi, *Why We Need Things* (1993)



Lattice bridge, Europe (location unknown) than something positive – it was expensive, difficult to manufacture, it failed without warning, and it rusted. An essential part of the solution to early-nineteenth-century bridge deficiencies and a key to the modernization of bridge building lay in the development of a structural system – in wood.

The lattice system, moreover, was greater than the sum of its wooden parts: the sides of the bridge could be built on land and subsequently moved into position. This prefabrication saved time and money not just in the building of one bridge, but in the construction and maintenance of thousands. The lattice bridge as an epochal industrial structural design, however, went unrecognized by historians. An important reason for its dismissal was its material. In the iron age, a 'wooden bridge' was a species low on the evolutionary scale of engineering. It hardly merited mention:

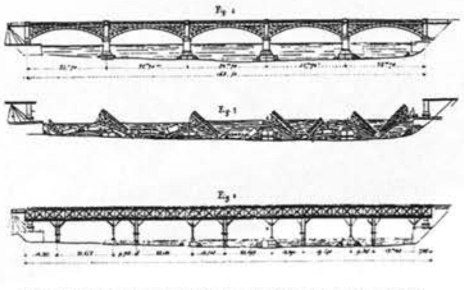
> *The construction of the first railroads greatly affected the development of strength of materials by presenting a series of new problems (especially in bridge engineering) which had to be solved. The materials used for building bridges were then stone and cast iron.* [17]

So began a discussion of iron tubular bridges by Stephen P. Timoshenko, professor of engineering mechanics at Stanford University when he wrote *History of Strength of Materials* (1953), a standard reference on the subject. Yet thousands of railroad bridges were built of wood. Timoshenko represents wood as a material of the past, the stuff of craft, provisional and cheap, although he does note that early metal bridges were 'similar' to existing wooden ones.[18]

The classifications 'wooden' and 'iron' in this context require re-examination, because many of the most well-known 'wooden bridges' of the eighteenth and nineteenth centuries had tons, literally tons, of iron, in the form of critical parts such as bolts, straps, and suspension rods. Iron played an integral role in these bridges, just as wood was central to the design of 'all-iron' bridges.

Builders seesawed between wood and iron. Around mid-century, the New York and Erie Railroad decided to replace its iron bridges with wooden ones after the collapse of an iron bridge patented by Nathaniel Rider; it seems that the railroad owners' financial interest in wood had something to do with it.[19] In a mirror-image action, the Compagnie de l'Ouest in France replaced its wooden arch bridges with cast-iron arches, in order to secure them against sabotage. (The oak and pine arch bridge at Asnières [1836], which carried three important rail lines to Paris, required major reinforcing and was burned during political upheaval of 1848.)[20] These were local movements in which 'evolution' encountered politics and not infrequently stalled or went into reverse. By 1854, wood had been banned for railways in the German states, although some engineers continued to use it, and by 1863, both wood and cast iron had been 'removed from the field of investigation: the former by negation, and the latter by direct condemnation.'[21] Inflammability and maintenance issues were 'obvious' reasons to reject wood, although only as obvious as local conditions; one historian reports that wooden railway bridges were common in the United States until the 1890s.[22]

As wooden bridges were rejected by the railways, the importance of the type of knowledge required to build with wood diminished. Because wood fails with forewarning, the carpenter could learn through observing and repairing his own work. The engineer using iron did not ordinarily have this opportunity, because iron breaks with no or little warning and does not lend itself to direct evaluation. He became more dependent on the manufacturer and mathematical calculation for the security of the bridge. The manufacturer became responsible for creating a material which met a specific stan-



Bridge, Asnières, France, Karl Etzel (1836: destroyed 1848)

There is generally sufficient evidence to warrant the view that the evolution of building techniques, like other inventive and creative activities, is an organic process. When the historian surveys the past, all that he really sees is an ever-branching continuity extending through all the aspects of culture. Technical invention reveals the same characteristic. It produces a series of mutations rather than a few original creations...The nature of invention in the nineteenth century and the requirements which motivated it were such as to exhibit to a striking degree the organic interrelations with technical processes and between such processes and utilitarian demands.

Historian Carl Condit, *American Building Art: Nineteenth Century* (1960)

dard; this standard was established by testing, which usually was done independently of the bridge designer. This 'liberation' of engineers from the material was an important factor in allowing the mass-construction of bridges.[23]

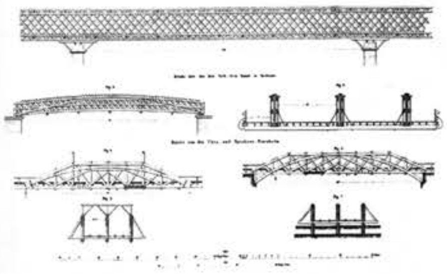
The professionalization of engineering coincided with the development of structural wrought iron.[24] Engineers imbued iron with the aura of progress and science, and it was upon iron and the methods of analysis developed at the time of iron's introduction that engineers maintained their status. The 'evolutionary' substitution of iron for wood in structures was accompanied by the lowering of the status of the carpenter – and the raising of the station of the iron engineer, who possessed a different kind of knowledge. As historian Joachim Radkau explains, craftsmanship and feeling for materials were still important, before iron and industrial building and after, but with iron 'human skill was pushed to the edge of the technologists' consciousness.'[25] Engineers knew, in any case, that to maintain their professional status, they needed to distinguish themselves from the fabricators and contractors whose participation in iron construction was essential.[26]

Iron is considered the classic material of the 'industrial revolution,' although lumber was no less an industrialized product, no less the stuff of 'revolution.' Many considered wood suitable for temporary structures or for nations on the other side of the 'great divide:' for less complex, less civilized societies. As historian Carl Condit asserted: 'Wherever wood was plentiful and industrial techniques less advanced than in Western Europe, timber construction was bound to be the natural choice.' For him, wood framing belonged to a 'vernacular tradition' – it was unscientific, practical.[27] From the evolutionary viewpoint, the wood-wielding inventors, builders, and engineers who developed our industrial technologies were primitives.

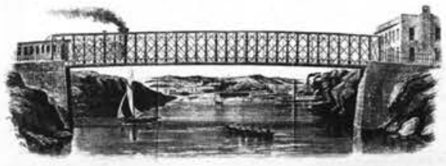
THE NATURE OF NATIONS

Technology was – and is – regarded as a defining element of national culture. Observers from Europe therefore examined 'American' technology at least as carefully as they examined American citizens. Like the naturalists and geologists who studied North American plants, animals, and rocks, engineers and entrepreneurs came to the United States to explore technology that could be of use to them. That a sparse population had built an enormous infrastructure within a few decades made the 'new World' an obligatory object of study. The missionaries of industry who stalked the latest inventions were as much technologists as promoters, politicians, proselytizers, and prophets.

The political and economic importance of transportation networks meant that many technological tourists scrutinized Town's lattice



Lattice and wooden bridges of North America (1850)



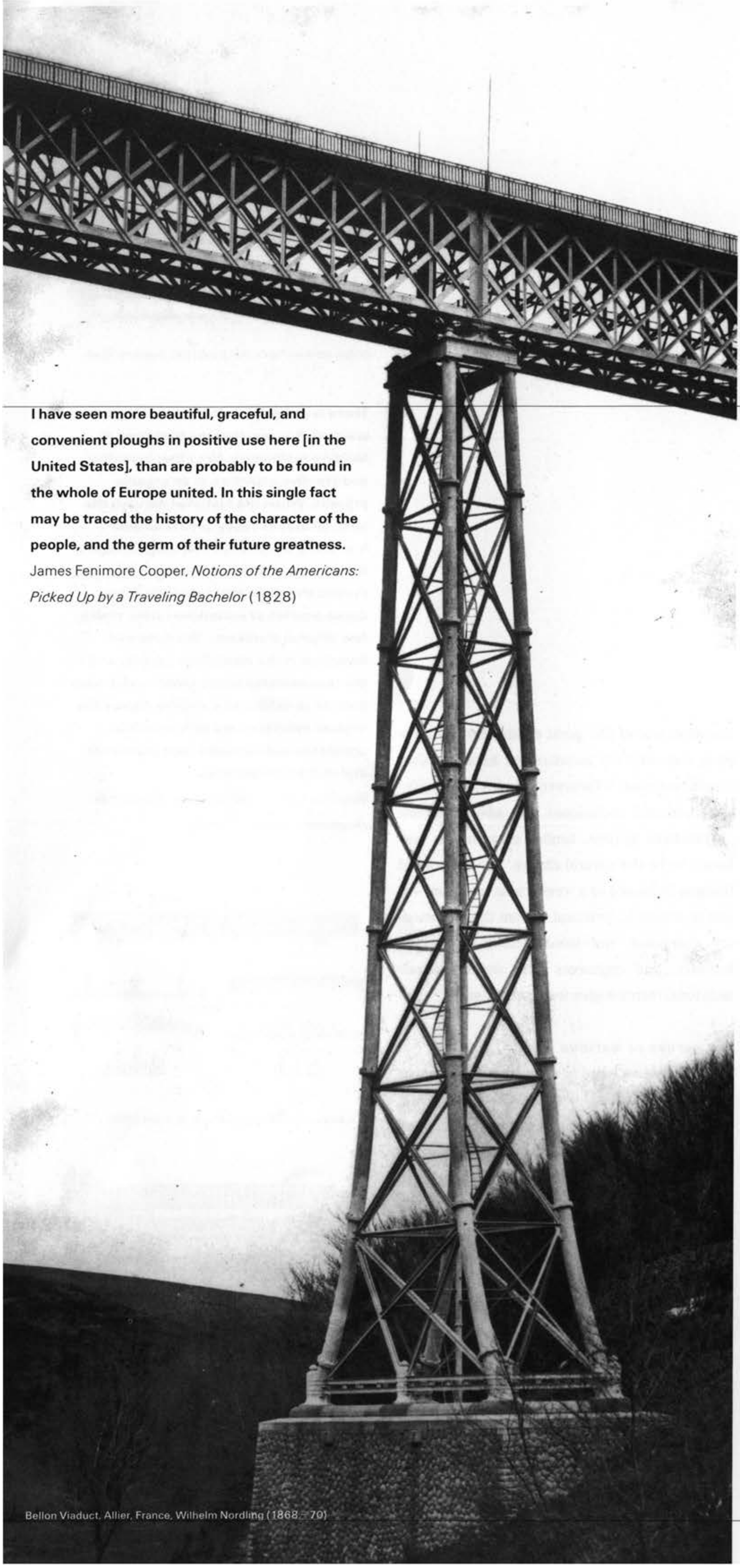
Rider's Bridge, advertisement (patented 1845)

Busseau d'Ahun Viaduct, Creuse, France, Wilhelm Nordling (1863-65) bridge and presented it to an international audience in professional books and journals. By the late 1830s, engineers had begun to build lattice bridges in France, England, Russia, Austria-Hungary, Prussia, Holland, and Ireland.[28]

As the United States and the states of Western Europe transformed themselves into industrial powers, the exchange of ideas allowed a scale of technological development that would not have occurred in one country alone. Building technologies flourished within a reciprocal relationship: exchange of information in these fields was essential for their development, and their development helped exchange to occur. The networks of roads and bridges essential for transportation, communications, defense, and trade were central to the physical and conceptual construction of nationhood. Despite – or because of – the transnational character of technological development, nations erected national identities along with their bridges.

Many historians who have examined building have transmitted nationalistic views with little interference. They used the technology transfer concept to characterize imperialistic activity as well as exchange between technological colleagues in America and Europe. 'Transfer' is based on the idea of technological firsts that acquire great significance within an evolutionary, nationalistic scheme. As a condition for transfer, the 'first iron bridge' existed in a particularly inventive culture, and bears the mark of that culture's 'character' or 'style.' Where the 'first' occurred, however, is often a matter of chance; for example the 'first iron bridge,' built in England, was preceded by others, including one over the Rhone in Lyon, a project that was aborted after the erection of the first arch because of cost.[29] When Condit wrote that 'the practical iron truss was initially a creation of American builders rather than European,' he was trying to claim iron as a first for the United States.[30] Iron bridges, however, weren't commonly built there until a few decades after such practice became common in several European countries. The development of the 'iron truss' was an endeavor that involved many countries – where the so-called 'first' all-iron truss bridge was constructed is just as unimportant for the overall history of structures as the fact that it was 'all-iron.'

The transfer concept reinforces the supposed separateness of cultures, nations, and materials. It works with the evolutionary scheme to support claims of national superiority. Strengthened by



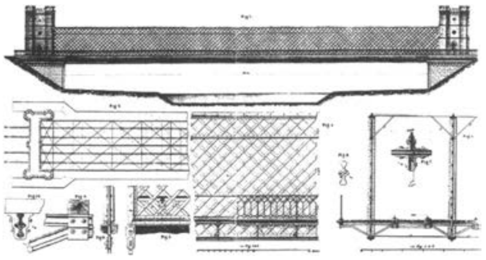
Bellon Viaduct, Allier, France, Wilhelm Nordling (1868–70)

I have seen more beautiful, graceful, and convenient ploughs in positive use here [in the United States], than are probably to be found in the whole of Europe united. In this single fact may be traced the history of the character of the people, and the germ of their future greatness.

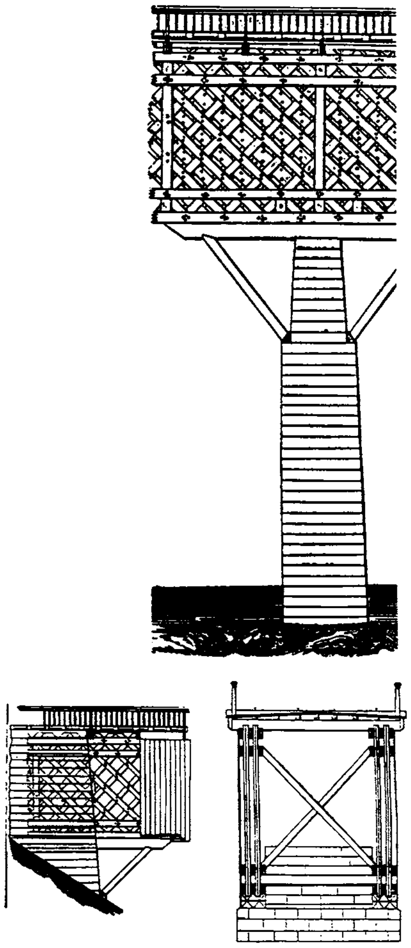
James Fenimore Cooper, *Notions of the Americans: Picked Up by a Traveling Bachelor* (1828)

One of the greats of France said: the style is the man. Isn't it just as appropriate to say: the works are the nation?

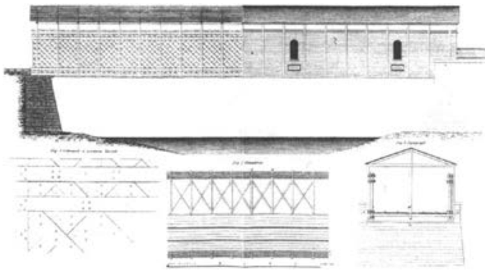
Engineer Berthault-Ducreux (1845)



Kinzig Bridge, Offenburg, Germany, Karl Ruppert (1852–53)



Peacock Bridge, near Reading, Pennsylvania, Moncure Robinson (1839-40)



Lattice bridge, Philadelphia-Wilmington Railroad, South Carolina (c.1839)

evolutionary theory, nationalism during the nineteenth century was a tool for the dominance and denigration of non-Western colonial populations.[31] Labels such as 'French' or 'wooden' were used in ways similar to racial classifications – ideology or politics were as important to labeling as any particular physical make-up. When races were considered by some to represent different stages of evolution, 'Anglo-Saxons' claimed to be at the high end of the evolutionary ladder and they touted their iron and steel as the highest achievements of civilized man.[32] Ideas of metal superiority and racial ideology became mixed: industrialists shipped iron bridges and buildings from Britain to India, the Bahamas and other colonies. These were areas which otherwise would have built with wood or other local materials.[33]

Is there an alternative to nationalistic evolutionary accounts of building history and the resulting view of structural design as an inevitable, heroic endeavor? One option is to regard the development of building as a process of exchange. Investigate the reasons why engineers choose or reject ideas and objects. Look at how ideas are interpreted and employed, and why. As obvious as they may seem, these strategies have often been ignored by structural designers and historians caught in a competitive and nationalistic environment.

Examining building as an exchange process would place engineering more firmly within the sphere from which it is often excluded – that is, 'culture' – because it would reconnect it to the 'non-technical' domains from which it sprang. It might broaden designers' options by encouraging them to reconsider notions of progress and categorization that serve to keep habits in place.

Mythical divides, intended to make reality graspable, result in narratives that do not accurately reflect design activity. Smashing the divides will help demystify design as it defuses nationalist explanation. A structure is a product of culture. It is the result of an intercultural exchange of things, techniques, and ideas. It is not individuals, however, but the relations between them that define design. If you want to understand a culture, look at its bridges.

[1] The term 'Great Divides' is used by Bruno Latour, who cites Jack Goody's expression: 'great dichotomy.' See Bruno Latour, "Drawing Things Together," in *Representation in Scientific Practice*, ed. Michael Lynch and Steve Woolgar (Cambridge, MIT Press, 1990), 19-20.

[2] The fact that the authors rarely explicitly state their theoretical foundation makes their histories no less theoretically based than those of authors who do. Some examples: Charles Davis Jameson, "The Evolution of the Modern Railway Bridge," *Popular Science Monthly* 36 (Feb. 1890): 461-481; J.E. Greiner, "The American Railroad Viaduct: Its Origin and Evolution," *Transactions of American Society of Civil Engineers* 25 (1891): 349-372; Charles C. Schneider, "The Evolution of the Practice of American Bridge Building," *Transactions of American Society of Civil Engineers* 54 (1905): 213-234; James K.Finch, "Wind Failures of Suspension Bridges or Evolution and Decay of the Stiffening Truss," *Engineering News Record* (27 March 1941); Llewellyn Nathaniel Edwards, *A Record of History and Evolution of Early American Bridges* (Orono, Maine: University Press,1959); Carl Condit, "The Two Centuries of Technical Evolution Underlying the Skyscraper," in *The Second Century of the Skyscraper*, ed. Lynn S. Beedle (N.Y.: Van Nostrand Reinhold, 1988), 11-24.

J. G. James acted as a Linnaeus of bridges; he received information from correspondents all over the world, just as Linnaeus received seeds and plants. James gave three of his bridge articles explicitly evolutionary titles: "The Evolution of Wooden Bridge Trusses to 1850," *Journal of Institute of Wood Science* 9 (1982): 116-135, 168-193; "The Evolution of Iron Bridge Trusses to 1850," *Transactions of the Newcomen Society* 52 (1980-81): 67-101; "Some Steps in the Evolution of Early Iron Arched Bridge Design," *Transactions of the Newcomen Society* 59 (1987-88): 153-87. James occasionally used evolutionary phraseology, e.g., he wrote of 'trusses reach[ing] a much higher state of perfection' ("Evolution of Iron," 84). He was trying to classify and link together all bridges in an evolutionary manner, but he did not explain why he was doing what he was doing.

Stewart Brand's idea of 'vernacular' architecture as evolutionary and 'visionary' architecture as non-evolutionary would seem to ignore the vision and failure behind vernacular architecture. It also seems to dismiss the 'vernacular' experience that is the foundation for 'vision.' Brand, after Darwin, substitutes 'vernacular' for the role of nature and 'visionary' for man. Brand, *How Buildings Learn* (N.Y.: Viking, 1994), 132-55; 188-89; see also Cornell, 332-333 (citation in note 10).

Among general evolutionary theorists of technology, S.C. Gilfillan, in *The Sociology of Invention* (Chicago: Follet, 1935; reprint, Cambridge: MIT, 1970), had a profoundly biological/anthropological view of technology. His aversion to the unthinking use of labels distinguishes his work. George Basalla in *The Evolution of Technology* (Cambridge: Cambridge University Press, 1988) begins his book, with its starkly philosophical title, by stating: 'This study is primarily historical, not an exercise in the philosophy or sociology of technology' (vii). A recent discussion of evolution as an explanation for technological development can be found in Joel Mokyøs, *The Lever of Riches* (N.Y.: Oxford University Press, 1990).

[3] Theodore Cooper, "American Railroad Bridges," *Transactions of American Society of Civil Engineers* (1889): 50.

[4] Re Spencer, see Richard Hofstadter, *Social Darwinism in American Thought* (1944, rev. ed. Boston: Beacon Press, 1955), 31-50.

[5] For example, Maximillian II in 1858 chose a Pauli bridge because it was cheapest and its creator was Bavarian. 'Konstruktion Eisenbahnbrücken und das von Pauli'sche Brückensystem,' Verkersarchiv Nürnberg #6823. Thanks to Helmut Hilz for this item.

[6] 'Sous la main de l'homme, les choses semblent s'animer, s'associer à ses aspirations et, comme lui, lutter pour l'existence': Jules Gaudard, *De l'évolution dans la construction des grands ponts* (Lausanne: Ch.Viret-Genton, 1892); George Michael Danko, "The Evolution of the Simple Truss Bridge 1790 to 1850: From Empiricism to Scientific Construction" (Ph.D. Dissertation, University of Pennsylvania, 1979), 72; Henry Petroski, *Engineers of Dreams* (N.Y.: Vintage Books, 1995), 36, and Petroski, *Invention by Design* (Cambridge: Harvard University Press, 1996), 204-05.

[7] See Chris de Bresson, "The Evolutionary Paradigm and the Economics of Technological Change," *Journal of Economic Issues* 21 (1987): 754-57. In addition to revival of the dead and interbreeding, de Bresson points out that technological evolutionists have trouble accounting for speed of innovative change and use of abandoned techniques.

[8] A second lattice patent was issued in 1835. Re Ithiel Town and the lattice bridge, see Gregory K. Dreicer, "The Long Span. Intercultural Exchange in Building Technology: Development and Industrialization of the Framed Beam in Western Europe and the United States, 1820–1870" (Ph.D. Dissertation, Cornell University, 1993) and forthcoming book. See also Richard Sanders Allen, *Covered Bridges of the Northeast* (Lexington, Mass.: S. Greene Press, 1957; rev. ed. 1983), and other books in this series.

[9] 'It is...extremely difficult even to conjecture by what gradations many structures have been perfected, more especially amongst broken and failing groups...which have suffered much extinction; but we see so many strange gradations...that we ought to be extremely cautious in saying that any...structure could not have arrived at its present state by many graduated steps.' Charles Darwin, *The Origin of the Species by Means of Natural Selection, or the Preservation of Favored Races in the Struggle for Life*, 6th ed. (London: John Murray, 1892 [1st ed: 1859]), 380.

[10] Darwin, *Origin*, 31. Darwin did not thoroughly examine his own technological analogy. See John F. Cornell, "Analogy and Technology in Darwin's vision of Nature," *Journal of History of Biology* 17 (1984): 317, n.46 and passim. It is very probable that Darwin (1809–1882) was aware of highly publicized civil engineering developments during his lifetime. One journal which he read, *Edinburgh Philosophical Journal* (see Peter J. Vorzimmer, "The Darwin Reading Notebooks (1838–1860)," *Journal of History of Biology* 10 (1971): 107–153) contained early reports of American bridges: e.g. Robert Stevenson, "Description of Bridges of Suspension," *Edinburgh Philosophical Journal* 5 (1821): 237–256, pl.8.

[11] Bernard, cited in Georges Canguilhem, "The Role of Analogies and Models in Biological Discovery," in *Scientific Change*, ed A.C. Crombie (N.Y.: Basic Books, 1963), 509. Evolution has often been characterized as mechanical; for example, J. Walter Wilson, "Biology Attains Maturity in the Nineteenth Century," in *Critical Problems in the History of Science*, ed. Marshall Clagett, (Madison: University of Wisconsin Press, 1959), 407 ff.

[12] Siegfried Giedion, *Mechanization Takes Command* (Oxford University Press, 1948, reprint, N.Y.: Norton, 1969), 31. Petroski tries to extract progress from technological evolutionism.

[13] If this goal is not defined, it cannot be determined if evolution is taking place. R. Puligandla, "The Concept of Evolution and Revolution" in *Evolution-Revolution: Patterns of Development in Nature, Society, Man and Knowledge*, ed. Rubin Gotesky and Ervin Laszli (N.Y.: Gordon & Breach, 1971), 42. Linear genealogies allow evolutionists to trace technologies to a "unique form." See Franz Boas, *Race, Language and Culture* (N.Y.: Macmillan, 1940), 290–94.

[14] 'The problem of the house has not yet been stated.' Le Corbusier, *Towards a New Architecture*, trans. Frederick Etchells (London: Architectural Press, 1927), 102.

[15] Carl Condit, *American Building: Materials and Techniques from the First Colonial Settlements to the Present* (Chicago: University of Chicago Press, 1968), 94.

[16] Years later, virtually all of the sixty-three bridges of the first British railway were stone arches. Henry Booth, "Chemin de fer de Liverpool à Manchester: Notice Historique," *Annales des ponts et chaussées* 1/1 (1831): 86-89. See James, "Some Steps," 154-56, regarding the small effect of the Coalbrookdale Bridge on bridge building. Re doorknobs, see Steven Lubar, "New, Useful, and Nonobvious," *American Heritage of Invention and Technology* (Spring/Summer 1990): 14.

[17] Stephen P. Timoshenko, *History of Strength of Materials* (N.Y.: McGraw-Hill, 1953, reprint, N.Y. Dover, 1983), 156.

[18] Timoshenko, *History*, 184-86.

[19] Nathaniel Rider (1790-1848) patented one of the earliest cast and wrought iron framed bridge systems; Victor C. Darnell, "The Pioneering Iron Trusses of Nathaniel Rider," *Construction History* 7 (1991): 69-81.

[20] Georges Ribeill, "Vie et mort des ouvrages d'art: l'exemple des ponts de chemins de fer," (Manuscript, 1992), 7. In the Asnières bridge, the wood rotted and the bolts that held the arch planks together had become 'Wasserleiter' (water pipes). "Ueber die Dauer hölzerner Brücken," *Allgemeine Bauzeitung* 27 (1862): 81-82. Re the wood versus stone debate, see Forest G. Hill, *Roads, Rails and Waterways: The Army Engineers and Early Transportation* (Norman, OK:U. of Oklahoma Press, 1957), 104; James D. Dilts, *The Great Road: The Building of the Baltimore and Ohio, The Nation's First Railroad, 1823–1853* (Stanford, CA: Stanford U. Press, 1993), 70, 73–79. For a recent chapter in the wood vs. metal story, see Eric Schatzberg, *Wings of Wood, Wings of Metal: Culture and Technical Choice in American Airplane Materials, 1914–1945* (Princeton:Princeton U. Press, 19980.

[21] C. Couche, "Travaux d'art des chemins de fer d'Allemagne" *Annales des mines* 5/5 (1854): 311-12; Robert Crawford, "The Railway System of Germany," *Transactions of Institution of Civil Engineers* 22 (1862-63): 13.

[22] J.G. James, "Overseas Railways and the Spread of Iron Bridges, c. 1850-70," (Published by author, 1987), 27.

[23] Re wood construction, see Milton S. Graton, *The Last of the Covered Bridge Builders* (Plymouth, NH: Clifford-Nichol, Inc., 1978), 1–5,9. The different knowledge required for wood and iron bridges, respectively, can be seen in an engineer's advice: "Neither is it safe to entrust light iron bridges wholly to the care of workmen not technically educated; the timber parts of wooden ones maybe;" J.P. Snow, "Wooden Bridge Construction on the Boston and Maine Railroad," *Association of Engineering Societies Journal* 15 (1895): 39.

[24] Robert Thorne, "Introduction," in Robert Thorne, ed., *The Iron Revolution: Architects, Engineers and Structural Innovation, 1780-1880* (London: RIBA Heinz Gallery, 1990), 7.

[25] "Mit der übergang vom Holz zum Eisen wurden doch ganz neue Perspektiven für die Organisation des Produktionsprozesses eröffnet, die die menschlichen Fertigkeiten im Bewußtsein der Techniker an den Rand rückten. Joachim Radkau, *Technik in Deutschland: vom 18. Jahrhundert bis zur Gegenwart* (Frankfurt: Suhrkamp, 1989), 63.

[26] Thorne, "Introduction," 8.

[27] Condit, "Building and Building Construction," 1: 373 and Condit, *American Building Art*, 16.

[28] Major-General Howard Douglas, *Essay on the Principles and Construction of Military Bridges*, 2d ed. (London, 1832); Guillaume-Tell Poussin, *Travaux d'améliorations intérieures projetés ou exécutés par le gouvernement général des Etats Unis d'Amérique de 1824 à 1831* (Paris, 1834-36); David Stevenson, *Sketch of the Civil Engineering of North America* (London, 1838); Michel Chevalier, *Histoire et description des voies de communication aux Etats-Unis* (Paris, 1840-41); Franz Anton Ritter von Gerstner, *Die innern Communicationen der vereinigten Staaten von Nordamerika* (Vienna, 1842); Karl Culmann,"Der Bau der hölzeren Brücken in den Vereinigten Staaten von Nordamerika . . . in den Jahren 1849 und 1850," *Allgemeine Bauzeitung* 16 (1851): 69-129; pls. 387-97 and "Der Bau der eisernen Brücken in England und Amerika," *Allgemeine Bauzeitung* 17 (1852): 163-222; 478-487.

[29] Bernard Marrey, *Les ponts modernes: 18e-19e siècles* (Paris: Picard, 1990), 105, reports that it was in 1755; Georg Christoph Mehrtens, *Vorlesungen über Ingenieur-Wissenschaften 2, Eisenbrückenbau* (Leipzig: Wilhelm Engelmann, 1908), 268, gives the year 1719 and the engineer's name Garrin.

[30] Condit, *American Building*, 94. Earlier, in *American Building Art: Nineteenth Century* (N.Y.: Oxford University Press, 1960), 4-5 Condit stated: 'Most of the fundamental inventions in nineteenth century construction, such as the iron frame, bridge truss, and arch, were European accomplishments. American work, with some important exceptions, consisted of adaptations of the original forms rather than innovations.' Daniel L. Schodek, 'clarifies' the issue in Landmarks in American Civil Engineering (Cambridge: MIT Press, 1987), 73: 'The development of the all-iron truss is fundamentally an American accomplishment, although the truss form itself has European precedents and all-iron forms have their European counterparts.'

[31] Michael Adas, *Machines as the Measure of Man: Science, Technology, and Ideologies of Western Dominance* (Ithaca: Cornell U. Press, 1989), 307–318.

[32] Thomas F. Gossett, *Race: The History of an Idea in America* (Dallas: Southern Methodist University Press, 1963), 144.

[33] James, "Overseas Railways": Gilbert Herbert, *Pioneers of Prefabrication: The British Contribution in the Nineteenth Century* (Baltimore: Johns Hopkins University Press, 1978); Charles E.Peterson, "Early American Prefabrication," *Gazette des Beaux-Arts* [NY] 33 (1948): 37–46.

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