Patterns of Thought as Contributors to Design and Construction

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ABSTRACT: This is a speculative paper, one that attempts to suggest a new perspective on our modern construction thinking, which is far more complex than we have thought it to be until now. It does this by beginning to examine an alternative to the traditional school of scientifically based thought. There are as yet no firm conclusions, only vectors, but these demonstrate that pre-scientific, empirical 'overlay thinking' survived as a complement to scientific 'model-thinking' and influenced it. The concepts explored here are: hybrid overlay, process, association, and problem avoidance. Two nineteenth-century, German-trained builders: John Roebling and Karl Ludwig Althans serve as the prime examples, but there are surely others, also in other cultures. The further development is indicated with the introduction of the concept 'problem avoidance' in American examples.

It is always difficult to trace the genesis and development of thought processes, especially over generations and in disparate objects. Postulating a beginning is arbitrary and determining which carriers build upon this beginning and carry the development forward depends on how one chooses the subjective criteria with which the development is measured. In construction history there are four possible carrier types to choose from: builders, manufacturers and fabricators, theoreticians (in which category I include designers and calculators), and educators. A 'school of thought' appears when all four types interweave successfully. Often, and especially at the beginning of a development, the subjects one chooses belong to two or even all of these types at once, especially in periods of rapid innovation or change like the end of the eighteenth and the beginning of the nineteenth centuries. Thus, the generally accepted development of modern building thought in construction and engineering starts with the development of modern scientific thought in Europe or perhaps in the following century or so in a more focused fashion with the Encyclopédistes in France. It jells with the foundation of modern engineering theory and building schools there, and gradually proliferates (as documented for theoreticians by Todhunter and Pearson 1886/93, Timoshenko 1953, Szabó 1976, Charleton 1982, or in a more sophisticated complexity by Kurrer 2002).

The theoreticians and educators who developed this French system of thought strove to clarify building types as they defined and designed simple, two-dimensional models: beam, column, arch with a number of subtypes like cantilever, continuous beam, the articulated beam and later frame, or the true or cantilevered arch. Connections between elements were either fixed or articulated. The goal of these simplifications was to render such structures comparable whatever their size and scale, to render them reliably calculable, and to ensure that they would behave predictably. Practitioners followed the theoreticians and simplified their structures according to these models. This impoverished structural invention on the one hand, especially at the beginning when two-dimensionally extruded structures dominated (and often they still do), but it did make a reliable prediction of safety and economy possible.

Economically this made eminent sense and this school of thought proliferated correspondingly. If we look more closely at the archetypes these builders and thinkers used we realize that they are models in the sense that they are simplifications and not true representations of actual structural behavior, which is always more complex and three-dimensional. Their drawback lay in the unfortunate fact that unreflecting practitioners and even some educators forgot that they were unclear mirrors and not structural reality.

THE ROEBLINGS AND OVERLAY THOUGHT

One of the types that escaped this simplification is the suspension system even though it developed at the same time and in part in the same sphere of influence in which the French 'model school' evolved. The reason for this was the need to stabilize an inherently labile form especially against wind forces that act largely perpendicularly to the two-dimensional model. Builders accomplished this stabilization by overlaying the suspension model with another stiffening model, sometimes in the same plan, but often also using spatial solutions. Stability could not be achieved within the model; it had to be overlaid with another. This overlay of simple or more sophisticated models to create a hybrid, working structure follows a pre-theoretical idea, 'overlay thought' which was first introduced by Hauri (1979, p.153-57). One of the characteristics of such overlay structures is that they do not define uniquely pre-determined load paths, but are ambiguous in that they can transfer loads in many ways all depending on the position and type of the load and the condition of the structure itself. This makes them more flexible and redundant. In the 'model school of thought', redundancy was achieved by introducing the concept of a factor of safety as a multiplicator of load assumptions; in the 'overlay school' redundancy was attained by providing the ambiguity of multiple load paths. Until now, this method has only been examined as a pre-scientific phenomenon, but here we trace it as a parallel method of thought into current practice.

Rarely do we consider such alternatives that developed in earlier times or perhaps paralleled the mainstream theoretical development and either enriched it, withered under its onslaught, or perhaps co-exist even today. Recognizing such alternate developments requires one to step outside our accepted patterns of thinking and choose other subjective criteria to determine carriers of the development.

One alternative type of building thought in building that derived from 'overlay thought' arose in the German-speaking world at the same time as the 'model method' developed in France. It is characterized by a less radical separation between theory and practice and therefore a more pragmatic approach to building types. This form of building thought co-exists even today, but it has attracted far less attention because it is not as conceptually distinct. There is no dichotomy between theory and practice and therefore no dialectic between them. Sometimes this form of building thought even contradicts theory without, however, attempting to change it. We call this 'empirical'. This makes it difficult to examine and define the tenets of this thought mode because it does not fit the standard pattern of historical discourse and certainly not a Marxist or dialectic approach, even though its origins appear to lie in German culture.

Perhaps it is best to start with the most eminent practitioner of this mode of building thought, and one who worked during the full flowering of the 'model method', John Roebling (1806-1869), and then to examine where he came from intellectually and where his thinking later led. Roebling's chef d'oeuvre is, of course the Brooklyn Bridge, and even that fact is ambiguous as it was actually designed and built according to his system by his son Washington Roebling (1837-1926) and the thinking of the father so conditioned the son's that we cannot easily separate them.

Built during the period of the most radical model simplification, Roebling and his son insisted on an overlay configuration of models: diagonal stays for stiffening (which both declared could bear the load on their own and which proved the bridges safety and redundancy), a primary catenary system, sidesway cables under the deck, and a stiffening truss that partly lay above the main cables on the Manhattan side. This last feature was less clear than the other elements that resemble 'models' in their purity, but it is typical of overlay thinking and may have been thought to improve the interaction between cable and truss by simultaneously stiffening the cable further from above and helping to support the truss from below. The truss ambiguously both carried and was carried by the cable structure. This is proven by the fact that it had, and still features, expansion joints at mid-span. There are four of these and their configuration was changed by David Steinman (1886-1960) in 1950 for traffic reasons without changing their ambiguity.

The father and son's insistence on the configuration of these many elements whose complex interaction they could only estimate approximately at the time, made the bridge's re-computation difficult for the restorers in 1983, but it has allowed the bridge to remain in use essentially structurally unchanged despite all increasing loading and material fatigue for over a century. In the 1983 restoration by Blair Birdsall (1907-97), the sidesway cables under the deck were removed. Although this may be structurally irrelevant it was historically an unfortunate decision because part of the complexity of the Roeblings' overlay-idea disappeared.


Figure 1, 2: Roebling's fishnet system on the Brooklyn Bridge

Nevertheless, the most essential feature of this unique bridge remains in place to this day, and that is the interlinking of the vertical suspenders of the catenary system and the diagonal stays from the tower to the deck. Both the suspenders and the stays are made of wire rope, which is more flexible than strain-hardened, parallel-wire cable. These are linked at every crossing by simple iron loops. In themselves these are not fixed connections, they slip. When taken as a whole, however, the 'network' exhibits the same behavior as a fishing net. When the loading of such a structure changes gradually with traffic movement as is the normal case, the individual links are not fixed and they can slide a little and adapt the geometry of the net to the load condition. But should the structure suffer a sudden impact, the links jam, adaptive movement is prevented, and the net behaves as though its connections were fixed. The curious fact is that the connection between two overlay systems created a new conceptual system in this case that fits the 'model-method'.

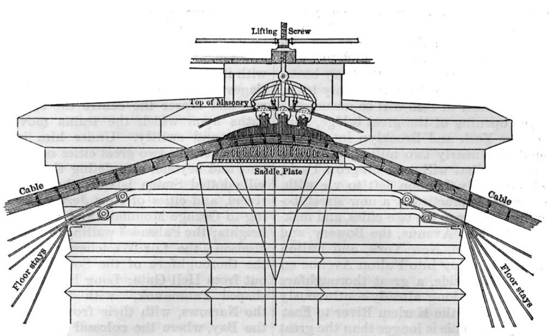



Figure 3 (left): Roebling's mobile cable saddle on the Brooklyn Bridge; (Harpers Weekly 1883); Figure 4 (Middle): The slipped and gummed-up rollers under the Brooklyn Bridge saddle; (photo: Thomas Zieman 1983); Figure 5 (right): Roebling's early fishnet on the Wheeling Bridge 1854

Nowhere does Roebling seem to express the fishnet idea in writing, but there is an indication that he may indeed have taken this effect into account in his design process because there is a very similar consideration that he did express about the cable saddles on the tops of the towers. Beginning with the Niagara Bridge of 1855, Roebling followed the French idea of allowing the main cables to slide back and forth over the tower tops to equalize changing cable stress on either side and thus relieve the masonry towers of lateral forces. In both bridges he arranged his cable saddles on a set of rollers that were to allow the whole saddle to move laterally. The idea did not work on the Niagara Bridge and the slender masonry pylons had later to be replaced by steel frames. He improved on the idea in Brooklyn, but there too the rollers slipped from their parallel position and were gummed up by dirt. The Brooklyn Bridge towers were massive enough to absorb the lateral forces.

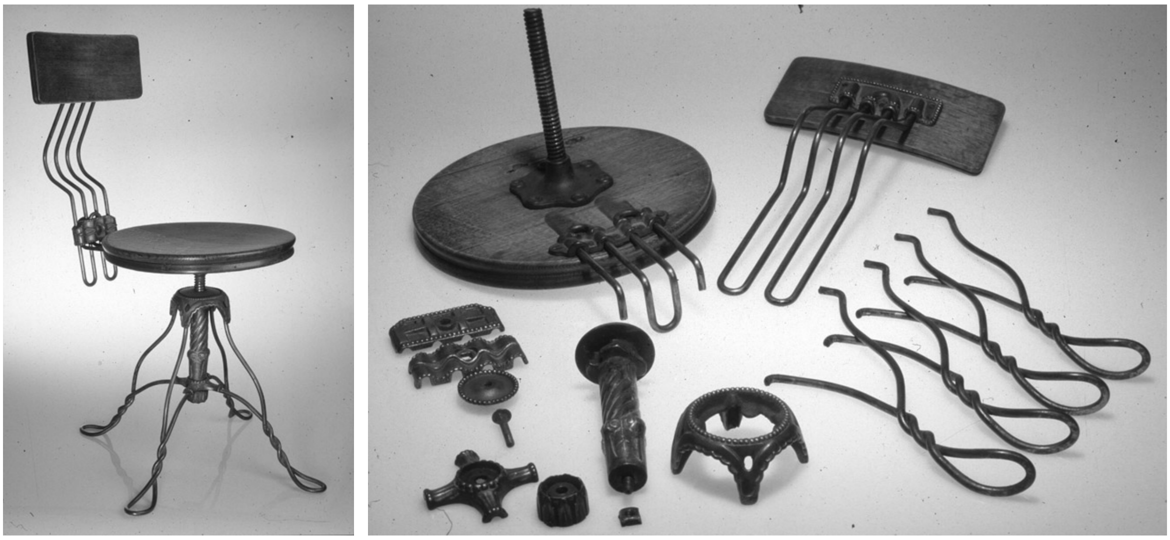
It is immaterial whether or not Roebling's ideas functioned as intended; it is the thought process that is important here. The 'ambiguous', fishnet behavior, in which structural response depends on a time factor, is not envisioned in the 'model method', but it works – at least in fishing.

We do not know whether the association with a fishing net occurred to Roebling or not, but it appears it was the father's and not his son's idea because it appears for the first time, albeit less clearly, in the 1854 reconstruction of the Wheeling Suspension Bridge over the Ohio River when the son was seventeen. At Wheeling the suspenders were iron rods, the stays wire rope, and the clamp provided a tighter connection than later at Brooklyn (at least in the version visible today). It is possible that the son modified the clamp in Brooklyn so that it could slip more easily.

Roebling also provided both stays and suspenders in all the variant designs that he proposed for the Niagara River Bridge between 1847 and 1852. (Werner 2006) In the first variant 1847 he used overlays of stays, suspenders, garland cables that Guillaume-Henri Dufour (1787-1875) and Marc Seguin (1786-1875) had developed in France and Switzerland in 1824, a wooden stiffening truss between the upper and lower deck, as well as supporting wooden struts and stays under the deck, which last Seguin and Dufour had also pioneered. In other words, Roebling envisaged using all possible ideas that had been proposed for suspension bridges previously except for counter cables that had first appeared on Marc Brunel's (1769-1849) Iles Réunion Bridges in 1822. (Peters 1987 p. 132)

The Niagara Bridge is interesting in the development of alternative thinking in that Roebling not only solved safety issues and design problems using the overlay method, but he also regarded building as a process. Considering the sequence in which a structure is built is incipient in all construction of course, but deliberate proc-

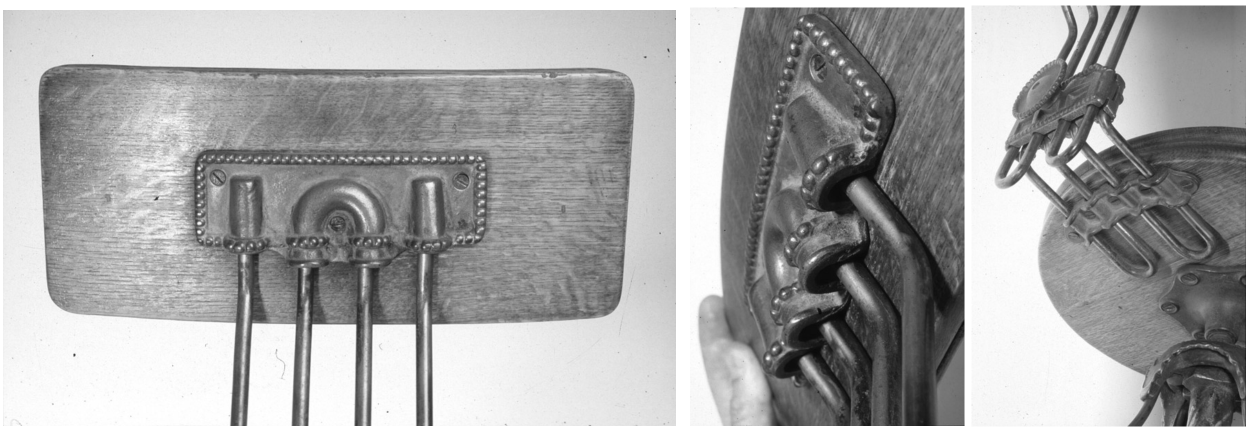
ess planning as a separate consideration in building was a novel idea at mid-nineteenth century. Process planning as a form of thought includes time as a parameter and the concept of the deadline as a limiting condition. It has been traced to Robert Stephenson's Menai Bridge (Peters 1996, p. 159 ff) between 1846 and 1850, but in a very different manner from the way Roebling used it in building the Niagara Bridge. His goal was the same: to save time and effort, and his sketch for a mechanized cable-spinning method dated 1846 introduces the method that in essence is still used today.
Roebling was not the first to use cable spinning. Louis-Joseph Vicat (1786-1861) had suggested it in 1830, and Joseph Chaley (1795-1861) had used a laborious, manual cable-spinning method on several of his bridges including those that featured his unique endless-cable system (Peters 1987, pp. 151-53, 161-64). It is possible that Roebling knew of Vicat's idea but almost certainly not Chaley's use of it that was only published much later and in an obscure article. The important point was that he mechanized the method and rendered it rationally time and effort saving in a modern process.



Figures 6, 7: Herbert Andrews's 'type-writer's chair' 1896

HERBERT ANDREWS'S CHAIR

The production process became of importance in industrially produced objects around this time, for instance in the first adaptable 'type-writer's chair', patented in the US under number 552502 on January 7th, 1896 by Herbert L. Andrews of Chicago. (Peters 1990, p. 149). This chair, an early example of a 'kit-of-parts' thinking in prefabrication was first noted by Sigfried Giedion in Mechanization takes Command in 1948 (p. 405) and by the Italian designer Mario Bellini in an article in Domus October 1986. The chair also displays a curious and inherently Anglo-Saxon variant of overlay thinking in an abstract sense that one might term 'problem avoidance' rather than problem solution. In the patent description, Andrews describes his chair as adaptable to an individual user. He achieved this adaptability through the use of what a conceptual designer working from a 'model' concept of connections: as either fixed or articulated, would describe as 'faulty' connections.



Figures 8, 9: the wiggling back bracket on Andrews's chair;
Figure 10 (right): the slipping seat clamp on Andrews's chair

The backrest is attached to the seat by means of a snaking vertical wire that can flex a little when the sitter leans back. Not only that, but the vertical wire attaches to the backrest by means of a bracket that must wig-

gle. It cannot clamp the looped wire firmly. Andrews designed the lower part of the bracket slot wider than the upper, thereby accentuating the wiggle and making the backrest tiltable.
The same is true for the attachment of the wire to the seat. This bracket cannot hold the wire loops tightly either and must slip. So Andrews made the wire loop under the seat longer so that the wire can slip back and forth in the bracket, thereby lengthening the distance from the back to the seat surface. Whatever the distance of the wire to the seat, when the sitter leans back, the horizontal part of the wire will clamp tightly against the underside of the seat and the bracket will jam tightly until the sitter leans forward again and releases the clamped wire. Andrews avoided the problem of the 'poor' connection by accentuating the problem and created thereby a new quality: adaptability. This is not a conceptual solution driven by model-thinking; it is empirical and incalculable by means of any theory of the period, but it works.
If we then look back on Roebling's partially slipping connection between the suspenders and stays in the Brooklyn Bridge we note the same type of incalculable and yet very workable solution. All three issues we have examined: the fishnet, process planning, and the clamping effect are time-dependent. Time, a new dimension that was not included in the 'model-method', entered design and construction.

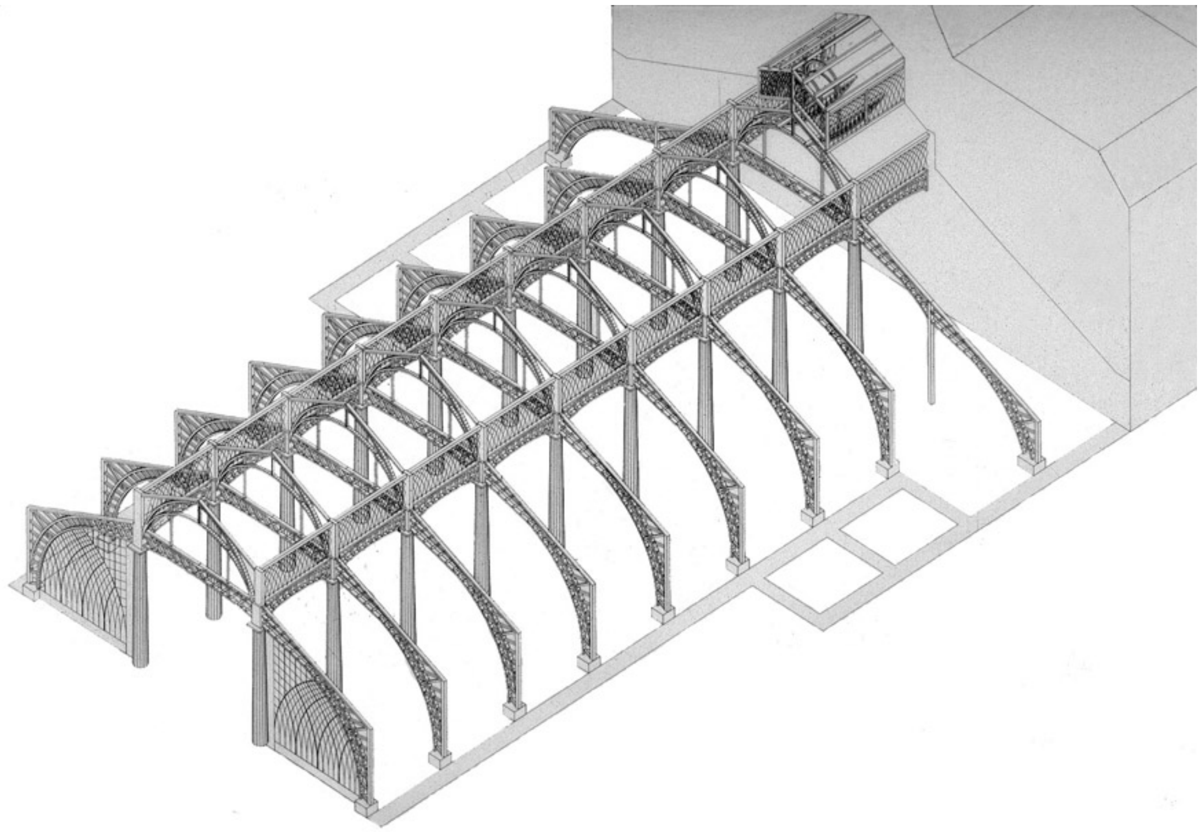
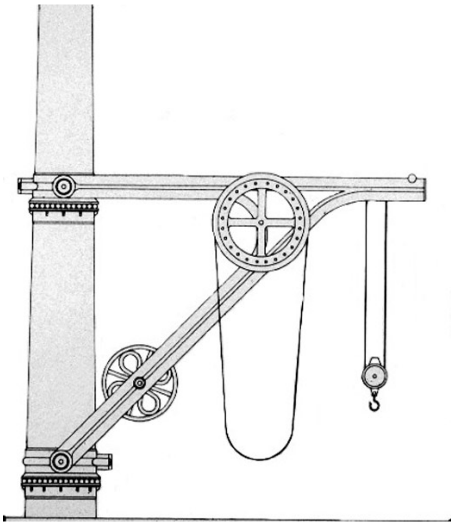


Figure 11: Sayn Foundry 1830 axonometric; (drawing Zarli Sein)

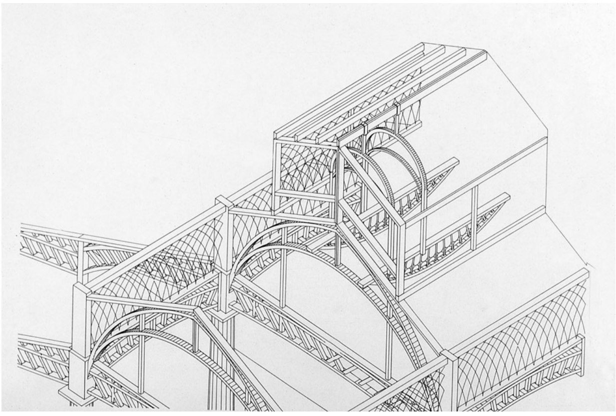
LUDWIG ALTHANS AND ASSOCIATIVE DESIGN

Alternate ways of thinking about construction were not restricted to the Anglo-Saxon world in which Roebling flourished, however. A builder who belonged to the preceding generation in Germany, Karl Ludwig Althans (1788-1864) also used a form of design thought that differed from model-thinking. As his son Ernst reported (1882, p. 171), Althans had studied at Göttingen University under Friedrich Hausmann, Johann Beckmann's student and successor who taught iron metallurgy, and the mathematician and astronomer Carl Friedrich Gauss. (He also erroneously wrote that he had studied with Thibaud who was at Heidelberg). Althans was thus eminently qualified in mathematical and scientific thought and certainly familiar with the latest developments in French thinking. This explains his intellectual background but not the source of his original design thinking because his teachers were all theoreticians and scientists. More research is needed to trace that, because in his best known surviving structure, the Sayn Foundry in Bendorf, the first phase of which was finished in 1830, Althans manifested an associative design thinking that differs drastically from the science-based thinking of the model-method. Associative design in Althans's work reminds one of Roebling's later fishnet-idea.




Figures 12; 13: Sayn Foundry, the swiveling crane with ball bearings; (drawing: Sein)

In the Sayn foundry, cannonballs became ball bearings for a swiveling crane. This was the first instance of their use in the Western world (Needham claimed their first invention for second-century China).




Figures 14; 15: Sayn Foundry, the gantry crane with steel spring lower chord; (drawing: Sein)

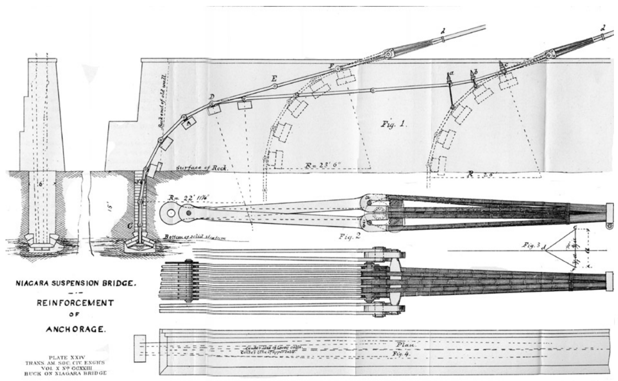
In another detail, a steel wagon-spring became the lower chord of a novel structural form, the fish-belly truss. In further association, the hollow columns of the structure were conceivably designed to be visual proof of the foundry's capacity to cast large cannon, while the foundry structure itself formed a hybrid overlay of cast-iron arches, struts and trusses. (Peters 1996) This last is why the highly redundant, though brittle structure has survived.

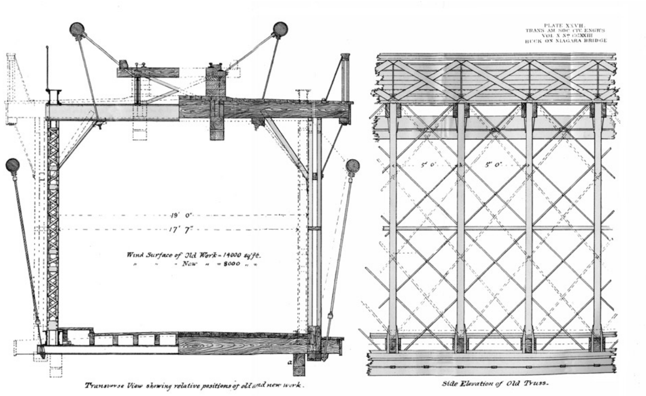
WHERE DID THIS COME FROM?

Many open questions remain about the origin of this non-scientific way of thinking in Germany. In part it derived from pre-statics thought that reaches back into pre-history, but in part also from traceable sources. One theoretical line seems to point to the Collegium Carolinum, now the TH in Braunschweig, and the University of Göttingen with Johann Beckmann and his intellectual descendents. Another, more pragmatic and industry-bound line points to David Gilly (1748-1808), who founded a private school in 1793 and then co-founded the first professional building school in Germany, the Berlin Bauakademie five years later. According to Lorenz (1995, p. 71), Gilly insisted on the 'Baumeister' or contractor model for professional education rather than on the separation between architect and engineer as in France. Gilly taught Karl-Friedrich Schinkel of whom it has been said that he died a little too early to have profoundly influenced the advent of iron technology into building that arrived in Germany with the explosion of industrialization shortly after mid-century. However Schinkel's celebrated Bauakademie (built 1832-36) presages the formal expression of an iron frame as it was being developed in England and France at the time at a very early date. It is futile to speculate upon what this may have meant for his further professional development, however Schinkel's pupil, Friedrich-August Stüler (1800-65), who hailed from the same small town as Roebling, did actively participate in the incorporation of iron into structure, as the ongoing restoration of his Neues Museum on the Museumsinsel in Berlin (built 1843-55), his involvement with the iron, box-girder Vistula Bridge at Dirschau (built 1851-57), and his construction of his friend Eduard Knobloch's Neue Synagoge in Berlin (built 1859-66) with the young, thirty-six-year-old railway engineer Johann Wilhelm Schwedler's (1823-94) famed iron dome structure, testifies. Lorenz (1995) carefully analyzes Schinkel's, but also Stüler's and Börsig's relationship to scientific-based thought, construction, and iron. On the other hand, the associative relationships, especially strong it appears in Börsig's work, have yet to be discussed. So do the personal influences. Roebling and Althans appear not to have met, but the question arises whether Roebling and Stüler knew one another, and it is possible but unlikely. It is true they came from similar social backgrounds in Mühlhausen, Roebling the third son of a tobacco manufacturer (Güntheroth 2006) and Stüler the son of a pastor, but Stüler was six years his senior, and in youth, that generally prevents more than a passing acquaintance. Rumors have it that the two met and even were friends in Berlin while Roebling was at the Bauakademie and Stüler a young architect, but again, Roebling left the country before Stüler's career flowered and the interest of both of them for iron structure matured.

LEFFERT BUCK EXPANDS OVERLAY THINKING

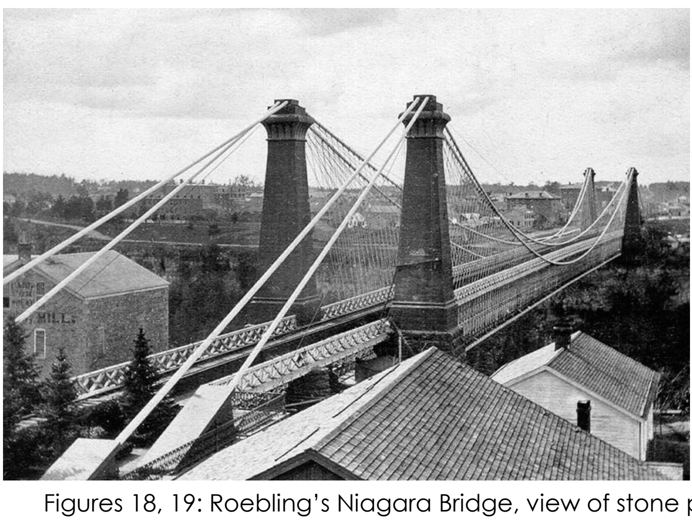
The history of the Niagara Bridge after Roebling's involvement further demonstrates the impact of non-model thinking in construction. Leffert Lefferts Buck (1837-1909) is an almost forgotten engineer, but he calculated and was involved in the erection of the highest bridge in the world around 1870, the Varrugas Viaduct on the Oroya Railway line in Peru. He also designed and built the Niagara Arch Bridge, the longest arch of its time, replacing Roebling's bridge in 1898, and New York's Williamsburg Bridge 1903 that remained the world's longest suspension span until the 1920s. In 1880, while Washington Roebling was building his father's final masterpiece, Buck was hired to strengthen and renew the Niagara Suspension Bridge that had suffered under train traffic.





Figures 16; 17: Buck's strengthening of the Niagara Anchorage 1880 and his replacement of the wooden truss with steel; (Trans. ASCE 1887)

In 1880 he reinforced the anchorages by overlaying them with a new anchor that he attached to the existing ones, and he replaced the wooden stiffening truss with iron, weaving the new members into the old without closing the bridge to traffic.



Figures 18, 19: Roebling's Niagara Bridge, view of stone pylons 1855 and Buck's steel replacement 1886; (source unknown and Trans. ASCE 1887)

In 1886 Buck built new, steel towers around the old masonry ones that had cracked because Roebling's movable cable saddles had jammed. Again, he overlaid the existing structure with a new one before removing

the old to guarantee the uninterrupted functioning of the bridge. Buck thus gave the overlay method a new justification by linking it to temporal issues in construction. When he finally replaced the Roebling structure with his own arch bridge in 1898, Buck once again overlaid the new structure on the old by building in and around it before removing Roebling's bridge and transferring the traffic load.
The conceptual elements of redundancy through hybrid overlay, the time-bound issues of the building process, associative design, and problem solving through avoidance are perhaps only a few of the non-model issues that this form of thinking contributed to our construction thought. There may be more. The examples cited here are all historical and all Western, but other cultures knew similar forms of non-model thinking, for instance the basket-like construction of the 'Rainbow Bridge' in twelfth-century, Song-Dynasty China that behaves structurally as a hybrid of arch and beam (Barnes 2000), and there are also cases of non-model thinking in current construction. As the engineer Leslie E. Robertson (b.1928) explains, the vertical space frame he designed for the Bank of China Building in Hongkong (built 1989-92) is unusual in that the hollow steel tubes of the frame are filled with unreinforced concrete, and despite the skepticism of theoreticians, they are able to transfer all loads and withstand all stresses adequately.

CONCLUSION

Technological thought in building is a complex construct. It underlies all design and construction and provides the theoretical underpinning of the creation of the built environment. Thus far, only part of the picture, scientific-based model-thinking has drawn the attention of researchers and this needs to be supplemented by other modes of thought that stem from earlier periods, parallel developments, and other cultures. Only then will we be able to understand how builders think in detail and what distinguishes building from other forms of human endeavor. This is a new area that merits further research.

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