Bridges have always fascinated both the layman and the professional. Their structural concepts are simple and visually easily understood: they are linear, carry traffic, and cross a gulf. Symbolically their concept is more complex: they span from one realm to another, cross the deep uncertainties of «troubled waters,» and connect. Bridges demonstrate human ingenuity and the triumph over nature, contradict the physical limitations of gravity by levitating traffic in the air, and make the impossible reality. Cultural historians and theoreticians love them, and it is not by chance that the Pope carries the title of pontifex maximus, the «supreme bridge-builder.»

Because of their linear simplicity and structural clarity, bridges also provide ideal case studies for that down-to-earth group that we represent, the historian of technology. They can teach us how diverse technological thinking is and how our viewpoint of technology changes over time and even how it varies between the fields of engineering, architecture, and construction.

Architects and engineers view the same thing from entirely different standpoints. For instance, a connection in the Bayonne Arch Bridge built in New Jersey by the engineer Othmar Ammann in 1931 gives differing information to engineers and architects (Figures 1 & 2). When asked what they see in the

Figure 1
Steel connection on the Bayonne Bridge over the Kill van Kull, New Jersey by Othmar Ammann, 1931 (photo: T. F. Peters)

Figure 2
The diagram of a «point» that the engineer sees in the connection (diagram: T. F. Peters)
connection, analytically oriented engineers will answer «a point» while architects see nothing «point-like» at all, but a formally incomprehensible mass of apparently haphazard steel members. Both observations are correct, they are just based on different interpretations of what is being looked at. Engineers instinctively translate what they see into an abstract model, a diagram, and they frequently block out the visual aspect, while architects attempt to recognize a formal logic or pattern. This is especially interesting to historians of construction because our field transcends the boundary between structural engineering and architecture.

Not only do viewpoints shift from profession to profession within the field of building, they also mutate over time. A shifting viewpoint changed bridge building in the nineteenth century and made it into a different field. If we look at plate ten of the first German treatise on bridge building published by Jacob Leupold in 1726 (Figure 3), we notice something curious. The two top diagrams are incomprehensible to us. They seem confusing and confused, while the four lower ones are clearly images of familiar truss bridges. It almost seems as though Leupold did not know what he was doing in the first two. But that cannot be. The six images form part of the same plate, so if the bottom four appear logical, we may expect that all six must follow some logic or other that we cannot decipher.

When we learn, however, that bridge builders in the eighteenth century tried to push the limit spans and loads of their bridges by overlaying simple structures that they were familiar with one on the other to achieve stronger and longer bridges, then the relationship between the two sets of images becomes clearer. The elements that they had at their disposal were the traditional king-post, queen-post, and slanted strut (Figure 4). By overlaying them one upon the other, builders could produce a stronger and longer bridge. They certainly did not know how to calculate and quantify their structural behavior, but they did know that they worked. The way that they explained how this design principle worked to their clients was to extrapolate linearly the loadbearing capacity of their simpler, traditional bridges. Caspar Walther wrote in 1766 that he demonstrated a tenth-scale model of a bridge he proposed to build to a client by putting ten men on it to show that the full-sized structure could carry 100! We know, and he knew too that his explanation was bogus, but he did not know why. Nevertheless, the bridges the contractors of the time built using overlays worked.

If we return to Leupold’s plate ten, we now read the four lower bridges in a new way. What we formerly looked at as the panels of a truss because of the way we have been educated, now appear as a series overlapping king- and queen-posts. And if we look closely at images three and five, we see that this must have been the way Leupold himself looked at them. The outermost diagonals of the bridges are doubled in these two examples. There is no structural need for them to be stronger than the others, but if we look at them as overlays we can see that the two
Figure 4
Hans Hauri, diagram of the basic elements of the traditional overlay system of bridge construction, used until the nineteenth century (From T. F. Peters et al, The Development of Long-span Bridge Building. 1979, Zurich.

layers belong to two different overlapped figures. Now that we understand how eighteenth-century bridge builders thought, we can easily analyze the most confusing bridge projects, like the one designed to span the Aare River at Aarau in Switzerland in the 1840s (Figure 5). Its logic is now clear to us, while formerly it would have appeared to us as an incomprehensibly complicated design by an ignorant craftsman.

Such shifts change the way we see understand problems and how we solve them. A view from outside a culture can expedite such change. When the young German engineer Carl Culmann came to the United States on a voyage of industrial espionage in 1850, one of the bridge types that fascinated him was the Whipple Truss. Squire Whipple had patented it in 1841 (Figure 6). Nowadays an engineer would call it a simply supported beam because it transfers only vertical loads to its foundations. An architect would call it an arch with a tie rod because of its form. But in 1841 Whipple himself called it a suspension bridge because the primary member, the deck, is suspended from the arch. The three names are all correct: the beam describes its structural behavior, the arch its form, and the suspension bridge its construction. Whipple’s term shows that he had conceived the bridge as an overlay of overlapping king-posts (Figure 7) that he used to suspend the deck. But when Culmann saw it he understood it differently again. He did not look at the structural model, the form of the
Culmann had been educated in the French analytical engineering tradition, initiated in 1797 at the Ecole polytechnique in Paris and developed in the younger German engineering school he attended in Karlsruhe. The German system based its curriculum on a change the Ecole centrale had introduced in 1829. The first tradition initiated analytical thinking in building and the second introduced a practical, industrial component into design.

On the background of this development, Culmann shifted his viewpoint half a module from Whipple’s traditional overlay approach and saw what we now call panels. The diagram taken from his publication of his voyage in the Allgemeine Bauzeitung of Vienna proves it (Figures 8 & 9). This is only a slight shift in viewpoint, but a profound conceptual shift. It changed nothing physical in the bridge itself, but it changed how we see bridge building forever.

We find such shifts at key moments of change throughout building history. When Giovanni Poleni examined the cracking of the dome of Saint Peter’s Basilica in Rome in the mid-eighteenth century, he discovered that the line of thrust in an arch or dome was nothing other than the catenary, the line a suspended chain follows, turned upside down.

Figure 7
King-post interpretation of Whipple’s Bridge (diagram T. F. Peters)

Figure 8
Panel interpretation of Whipple’s Bridge (diagram T. F. Peters)

Figure 9
Illustration from Carl Culmann’s article of 1851 showing the Whipple Bridge. Allgemeine Bauzeitung, Vienna

Figure 10
Giovanni Poleni’s diagram of the inverted catenary as the line of thrust in a dome, from Memorie istoriche, 1748
(Figure 10). In other words, by inverting gravity he converted a suspension structure into an arch. Poleni’s discovery used physics as a tool, and it initiated «hard» analytical thinking into building. Inversion is one of the methods that can shift our viewpoint.

Robert Maillart experienced a similar shift in his viewpoint when his first independent structure, the small Zuoz Bridge over the Inn River in Switzerland twisted slightly and cracked its spandrels in 1901 (Figure 11). Any «normal» engineer would have been horrified and determined to strengthen the spandrels next time so that the failure would not occur again. But Maillart shifted his viewpoint and did the opposite. Since the bridge had not collapsed, he argued, the cracked spandrels must be redundant because they were still holding even though they were not carrying any load. So when he designed his next bridge, the Tavanasa Bridge not far from the first one in 1905 (Figure 12), he left them out and created a distinctive new bridge type. This type of shift never stops. Christian Menn did it again when he inverted the Tavanasa Bridge in 1980 and reinterpreted it as his prize-winning Ganter Bridge in the western Swiss Alps (Figure 13).

Our Western culture is not the only one to use shifts in understanding to innovate in bridge building. In 11th century Song-Dynasty China, a novel bridge type suddenly appeared that has no corresponding version anywhere else. The so-called «rainbow bridge» (Figure 14) has long been the object of
speculation in the history of Chinese bridges. Like the overlaid structures of the West, it does not behave according to modern statics, but depends on the pinching action of its woven form for its integrity. It seems to be an arch, but the strange thing, as the reconstruction of one in 1999 showed, loading it produces no thrust at the abutments. So it must be a simply supported beam, an engineer would say. But it has no tie rod like the Whipple bridge; so how does it work? Although we are not yet quite certain, it seems that the pinching action of the scissor-shaped connection (Figure 15), holds the crossbeams tightly and somehow takes up the forces that would otherwise flow along the arch-shape to the abutments. This may be analogous to the behavior of the intricate basket weaving that the ethnic group is known for that lives where this type of bridge first appeared. This explanation is, of course very much more speculative than the more easily proven examples from the West, but it is also almost 1000 years older and contemporary documents have long since disappeared.

There is one Western example that also uses pinching as a connection, and that is the first bridge over the Rhine that Julius Caesar is said to have ordered built for his conquest of the north (Figure 16). The Caesar bridge, of which we have only a reconstruction from the description, was a trestle construction with wedges set between the beams that carried the decking and the slanted posts that supported them. These wedges were so arranged that they bit ever tighter into the wood and pinched the beams as the deck was loaded. The solution was conceptually similar, and yet not as simple as the Song Rainbow Bridge, in which the deck beams themselves formed the wedges.

We can learn a great deal from bridges. By following the subtle clues they give us, we can gain insight into how builders used to think and how that thinking was similar to or different from ours. It is important for us as historians and educators to understand that technologists, all depending on their field, their education, their culture, and the period in which they live, can see and think in many different ways. It puts our own time, our own culture, and our own systems of thought into perspective, and that can, I hope, make us more receptive to innovative ways of solving our problems today.
NOTES
1. Jacob Leupold, Theatrum Pontificale oder Schauplatz der Brücken und Brückenbaues [sic] . . . 1726, Leipzig