Introduction

The life and works of Robert Maillart developed around one central issue of twentieth-century technological society: the debate between the applied science view and the design view of engineering, between the ideal of "one best way" and the belief in many possible best ways, between reliance on general mathematical theories for understanding engineering works and the inspiration of specific works already in service.

Maillart's life was a constant battle for the design view of engineering against the applied science view. The two competing perspectives gave rise to very different approaches to education, research, and practice. These differences in turn illustrate a wider division over modern technological society itself: between a view that favors centralized rational planning and central authority in society, on the grounds that these are the ways technology itself works, and a view that technology and a modern technological society can also favor decentralized, local, and diffused responsibility and a high degree of choice. It is no accident that Maillart was able to accomplish in Switzerland works that would have been difficult or impossible in the larger and more centralized nations of Europe.

No other structural engineer during the first half of the twentieth century so fully engaged in this debate over the real meaning of modern technology as Maillart. He taught and publicly attacked the applied science education he saw emerging in engineering schools such as his own in Zurich. He wrote heatedly against applied science research and he pioneered innovative research and design in direct opposition to authorities and peer groups that had been seduced by the applied science view.

In his own field of structural engineering, proponents of the applied science view saw education as the teaching of fundamental principles, general theories, and basic mathematical methods illustrated with abstract diagrams and algebraic formulations. Maillart himself had a quite different education that formed his view that principles ought to be illustrated by specific examples of actual structures and that methods of analysis should be visual. He later gave courses along these lines.

In research, structural engineers taking the applied science approach sought to discover general principles by the systematic study of the elements of structures (e.g., beams, columns, joints) under controlled laboratory conditions. Their goal was to write codes to regulate practice in accordance with research results. The measure of performance in concrete structures was taken to be stress (force per unit area) determined by complex mathematical theories. Maillart reacted strongly against this kind of abstract reductionism. Instead, he did his own research on large-scale models of real structures or on actual structures in service. His goal was to understand specific structural forms under actual service conditions so as to develop simplified but true calculations of their safety.

Maillart had an even deeper objection to the applied science view of practice: It discouraged real innovation. He found that innovation, especially in bridge design, came not from laboratory work and mathematical theories, but from design offices and construction sites. Numbers play an essential role in engineering. But innovation in bridge design was the product of a visual-geometric imagination, not the outcome of abstract numerical studies or deduction from general theories.

Maillart took an integrated view of structure that started with a geometric idea and then developed the calculations necessary to make it work. To design a bridge, the engineer must imagine how the weight will transfer from the bridge span to the supports, how the structure will be built, and what it will look like in service. These three aspects are independent and make the designer's task complex. Most engineers focus solely on the transfer of weight by accepting a standard frequently built form that is known to be safe. By contrast, the best structural designers keep all three criteria in mind. To do this, they rely on simplified calculations. These are not less rigorous or less accurate for being simpler; rather, they are another way to look at the structure, one that is visual as well as numerical, geometric rather than entirely algebraic, and one that suggests new forms.

Simplified calculations might be better called conceptual computations appropriate to the form being studied and not necessarily a special case from a general theory. But conceptual computations are also not merely preliminary ones; instead, the best designers use them to direct the design and often they are the only ones made. The crucial decision in structural design is always the chosen form and how this choice is made marks off two types of engineers: one who accepts traditional forms and relies on general theories and the other who questions these forms and looks for specific conceptual computational procedures.

Finally, in the applied science view, engineering practice was merely a working out of an optimum solution found by theory. The objective was to find the least expensive structure that satisfied the restrictions of a building code. Aesthetic appearance was either neglected or treated by the view that true economy would produce elegance. If more beauty was needed, then an architect could be employed to provide decoration or conceal the ugliness. To Maillart, such an approach to appearance was anathema. Appearance was to him the responsibility of the engineer and one of the tests of a good design.

In the late 1920s, a few writers popularized the view that engineering works could be works of art in the manner of architecture and sculpture. Writers such as Sigfried Giedion "discovered" Maillart in the early 1930s and began to publish photographs of his structures in modernist journals. These writers recognized that culture was being fundamentally changed by modern technology and they were searching for examples of modern engineering that combined both modern design and elegant appearance.

Maillart's design ideas owed nothing to such writings even though he certainly read some of them. Maillart's engineering vision had an entirely different origin: in the essence of structural engineering itself, in the geometric patterns of forces in reinforced concrete forms as they transmitted weight to the ground. A significant number of structural engineers have since recognized, as Maillart did, that elegant appearance could arise from the patterns traced by these forces. Elegance arose from the structure itself and not from an extraneous idea of beauty.

Maillart went beyond the structural engineers of his time in striving wherever possible for striking visual expression. This aesthetic motivation makes it possible to call him a structural artist. Yet he did not think of himself as an artist. He never used the term and he had little interest in contemporary artistic trends. He was not an artist in any sense that modernists understood the term. He was a modern figure with an aesthetic vision rooted in that defining characteristic of the modern world, its engineering.

CHAPTER ONE

Student and Designer
1872–1901

The Synthesis of Cultures
Bern and Zurich

BELGIAN AND GERMAN-SWISS

In the second half of the nineteenth century, the ideal Swiss city in which to raise a future bridge engineer would certainly have been Bern. The setting stimulates a bridge designer's imagination at once. Unlike Geneva, Basel, and Zurich, Bern was not in a strategic location for transportation and trade. Rather, its location high above a sharp bend in the Aare River made it an ideal fortress for the last Duke of Zähringen, who founded it in 1191.[1] Up until 1844, this natural, isolated peninsula was still almost completely unabridged. Even today, the old city of Bern gives the feeling of a stronghold. It is there that Robert Maillart was born on February 6, 1872.

His mother, Bertha Küpfer Maillart (1842–1932; Fig. 1), was German-Swiss and his father, Edmond Maillart (1834–74; Fig. 2), was Belgian. Robert was the fifth of six children, the first three of whom were born in French-speaking Geneva and the last three in German-speaking Bern. Thus, the Maillarts were culturally mixed: part of a native Swiss family (the Küpfers), and part of a displaced Belgian family (the Maillarts). Robert became a Swiss citizen in 1886. Maillart's great grandfather, Phillipe Joseph Maillart (1764–1856), was a well-known engraver and a painter.[2]

Both the Küpfer and the Maillart families were Calvinists, and this strict Protestant background may well have played a part in Robert Maillart's extraordinary self-discipline. Brought up in French Switzerland, as a youth, Robert's father began to study theology, presumably with the intention of becoming a minister, but a speech impediment deterred him and he entered the business of banking instead. On May 21, 1864, he married Bertha Küpfer of Bern and the couple settled in Geneva. Shortly after the birth of their third child the family moved to Bern where the other three, including Robert, were born. A mere 7 months after the birth of Maximilian, Edmond died suddenly (April 24, 1874), leaving his widow with five small children (one girl having died in 1873) and little money. Robert was only 2 years old when his father died, and he therefore had no memory of him.

The Küpfers were an old and well-known bourgeois Bernese family; Bertha's lineage can be traced back as far as Johannes Küpfer, a member of the Bern Grand Council in 1550.[3] Many of her relatives were ministers, many were in business, and one of her father's cousins, Ludwig (1803–79), was a Bern cantonal architect. Although she had only one sister, Bertha grew up within a large family of aunts, uncles, and cousins. Indeed, when her fifth child, Robert, was christened, the three godparents were all from her family, and when her husband died and left her practically destitute, it was one of her aunts who helped her financially.[4]

Robert Maillart's father spoke French as his native tongue and his mother German; together they conversed in French. But Robert's native language was German, which he always spoke with his

Figure 1. Bertha Maillart (1842–1932), mother of Robert Maillart. (*Source:* Madame M.-C. Blumer-Maillart)

Figure 2. Edmond Maillart (1834–74), father of Robert Maillart. (*Source:* Madame M.-C. Blumer-Maillart)

mother. She was his confidante, and from early childhood he developed a respect for her that sharply curtailed any kind of boyish misbehavior. He was so upset by the sorrow caused Bertha by his older brother Paul's misconduct that he resolved at an early age never to risk a similar affront.

Until the eighteenth century Bern was an imperialist capital whose leaders had conquered surrounding territories by force. Although modern Switzerland has no hereditary nobility, the conquering families of Bern took the aristocratic prefix "von." Their exclusivity had spurred the Küpfers to support an abortive revolt in 1749.[5] The Maillart family name is mentioned as far back as 988 in records of the region of Liège. In 1017, Jean Coley, dit Maillart, commanded a victorious army for the Bishop of Liège but was blinded in battle. This event is presumed to have been the origin of the French version of Blind Man's Bluff, known in French as "Colin-Maillard." With neither social position nor family wealth, Maillart grew up feeling that he was on the fringe of Swiss society. He and his brothers made their careers on their own merit and each married non-Swiss women.

Whereas it is clear that Robert Maillart inherited his mother's emotional stability and self-reliance, little is known about his father. Undocumented family legend has it that Edmond Maillart's banking partner, by some questionable practices, led Edmond into bankruptcy, an event that may have contributed to his early death.

Figure 3. Maillart Family, circa 1884, (*left to right*) Alfred, Bertha, Rosa, Paul, Max, and Robert. (*Source:* Madame M.-C. Blumer-Maillart)

DISCIPLINE AND PLAY

Robert Maillart would develop into a man focused, almost to the point of obsession, on work and family. He was indifferent to the performing or visual arts, read little, except for literature related to his profession, and had little interest in travel or hobbies. The one deviation from this single mindedness was his love of parlor games, which soon was focused on cards. What appealed to Maillart in these games was their combination of discipline – represented by the rules – and "play" or the freedom allowed by these rules.

In his book, *Homo Ludens,* the Dutch historian, Johan Huizinga (1872–1944), elevates playing man to a level of cultural significance equal to knowing (*Homo Sapiens*) and making (*Homo Faber*). Huizinga's description of play fits Maillart's attitude closely: "it creates order, *is* order. The least deviation from it 'spoils the game,' robs it of its character and makes it worthless. The profound affinity between play and order is perhaps the reason why play . . . seems to be to such a large extent in the field of aesthetics. Play has a tendency to be beautiful. It may be that this aesthetic factor is identical with the impulse to create orderly form, which animates play in all its aspects."[6] Maillart's career would center on structures that had to obey the rules of nature but within those rules allowed for the creation of new forms that grew from an aesthetic sensitivity.

Maillart's disciplined love of play appears in his early interest in chess. The seriousness with which he took the game – a seriousness that marked all his pursuits – is illustrated in the elegant and precise little journal he published in 1888–9 reporting on a teenage chess club of which he was secretary (also it would seem president, treasurer, editor, and chronicler). The names of thirteen young men appear in neat records of their wins and losses with Robert consistently the leading winner. In the journal, he laments that most of the club members did not take the game seriously enough.[7] But he also displayed a sense of humor in some of the writings. In an early family photo, only he exhibits the slight smile that would later characterize a quiet joi de vivre (right in Fig. 3).

The chess club membership, including young men from old established Bernese families (von May and von Tscharner), demonstrates something of the society in which Maillart grew up. He also had some contact with the city's artistic and intellectual elite through his close chess-playing friend, Fritz Widmann (1869–1937), who later became a painter and friend of Herman Hesse and Paul Klee.[8] But Maillart never felt at ease with socially or artistically prominent people and rarely saw Widmann after their boyhood friendship in Bern.[9]

Between 1885 and 1889, Maillart attended the Bern gymnasium, where he showed talent in mathematics and drawing. He excelled in both freehand sketching and technical drawing. In 1889, he passed the State examinations with 4.8 out of 6.[10] His grades qualified him for admission to the Federal Polytechnical Institute in Zurich (ETH), where he would study engineering. But being too young to enter, he went to Geneva for a year to study mechanics in watchmaking school.[11] This Geneva experience foreshadowed a critical aspect of his talent: He earned a 4 (out of 6) in practical work (watchmaking) and a 6 in design and in mechanics. His aptitude was obviously not for making things with his own hands, but rather for design and for the analysis of how things work.

With his stint in Geneva complete, in the fall of 1890, Maillart moved to Zurich to enter the 35-year-old ETH. The young man carried with him a strong bond to his family, and an independence of mind despite his restrictive upbringing. He had reflected on and developed many ideas on career, virtue, and religion, ideas that because of his natural reserve had not been tested in discussion.

ENGINEERING IN ZURICH: THE SWISS SYNTHESIS

Maillart entered the Federal Polytechnical Institute with a good grounding in mathematics and the sciences; he graduated 4 years later with the finest possible education in structural engineering. By the 1890s, the Institute was world famous; with many foreign students, it also educated more Swiss than the small country could support. Since its founding in 1855, the Institute had maintained the high standard established by two remarkable teachers, Carl Culmann (1812–81) and Karl Wilhelm Ritter (1847–1906). From the latter, Maillart learned to approach structures with a design view rather than with the view of an applied scientist.

Among the Institute's first appointments, civil engineer Carl Culmann (Fig. 4) was one of the four who were perhaps the best academics in their fields: the others were architect Gottfried Semper (1803–79), physicist Rudolf Clausius (1822–88), and historian Jacob Burckhardt (1818–97).[12] The contrast between Semper and Culmann characterizes the contrast between the world of architecture and that of engineering as the latter grew to prominence in nineteenth-century higher education. Semper (Fig. 5) practiced architectural design – he designed the first main building of the Institute (Fig. 6) built between 1858 and 1864 – he wrote widely on art and architecture, and he was politically active. His participation in the 1849 revolution in Dresden, where he was director of the Bauschule of the Royal Academy, forced him into exile in London. It was his Dresden friend and corevolutionary, Richard Wagner, exiled in Zurich, who recommended him for the position there, which he accepted in 1855.

Culmann, by contrast, did not practice engineering design once he came to Zurich; rather he served as a consultant on technical problems ranging from flooding mountain torrents to bridge building. He wrote not on accessible subjects like art, but in the

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More information

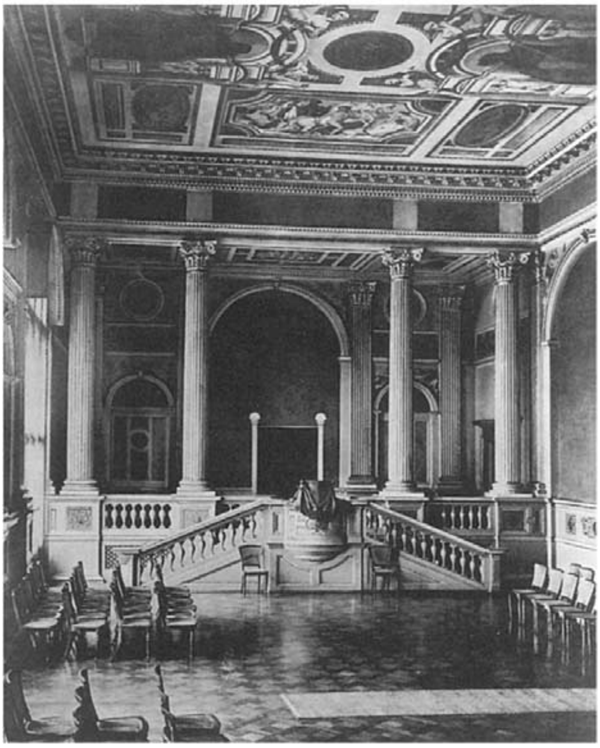

Figure 4. Carl Culmann (1821–81), founding head of the Civil Engineering Department at the Swiss Federal Polytechnical Institute in Zurich. (*Source:* Eidgenossisches Polytechnikum, Festschrift I)

Figure 5. (*upper right*) Gottfried Semper (1803–79), founding head of the Architecture Department at the Swiss Federal Polytechnical Institute in Zurich. (*Source:* Eidgenossisches Polytechnikum, Festschrift I)

Figure 6. (*right*) Federal Polytechnical Institute in Zurich. (*Source:* Eidgenossisches Polytechnikum, Festschrift II, p. 328)

specialized field of structural analysis, and he had little interest in politics. The formal portrait of Culmann in the ETH 50-year celebration book shows a serious middle-aged man in black suit and formal tie, whereas Semper's portrait has him sporting an ermine-collared cloak: the staid, conservative engineer and the fashionable, radical architect.

What was to become the highly influential modern Swiss bridge tradition began with Culmann. Born in Bavaria, Culmann studied French graphical analysis in Metz and then received a German engineering diploma from the Karlsruhe Polytechnic Institute in 1841, after which he worked for the Bavarian state railways until invited to Zurich in

1855.[13] In addition to gaining firsthand field experience with railroad bridges built during the early days of the German rail boom, Culmann took an interest in recently completed structures elsewhere, and in 1849–50, he made a 2-year trip to Britain and the United States to study their more advanced bridges and railways. Britain was still the leading industrial nation and its bridges represented the best designs built up to mid-century. The United States, however, was rapidly catching up and would soon dominate bridge innovation. Many of the best American bridge engineers were German-trained but had rejected German dogmatism. John Roebling, the most famous one, had been quite explicit about this and much like those of the Swiss, his great works combined ideas coming from Germany (his education in Berlin) and from France (parallel-wire cables for suspension bridges). The result of Culmann's trip was a widely read report.[14] He was a pioneer, possibly the first major European professor of structures to have made an extended study tour to specifically broaden his vision, rather than to develop foreign business connections.

Culmann also began detailed studies of structural engineering methods. Early in his teaching career, he started to systematize these studies, and, in 1866, he published them in *Graphic Statics*, probably the single most influential book in its field at the time.[15] His basic idea was to demonstrate structural behavior through geometric diagrams rather than through algebraic formulas. "Drawing is the language of the Engineer" he used to say, "the geometric way of thinking is a view of the thing itself and is, therefore, the most natural way, while with analytic method, as elegant as that may also be, the subject hides behind unfamiliar symbols."[16] Culmann imparted a sense of the three-dimensional reality of man-made structures set within the natural environment.

In Zurich, he founded an approach to design based on firsthand field experience, an international outlook, and a visual-geometric approach, all in sharp contrast to the algebraic approach taken by leading engineering teachers at the time. Because of his unorthodox methods, Culmann's influence might not have extended into the twentieth century had it not been for Karl Wilhelm Ritter, chosen to succeed him in 1882.

RITTER AND THE BRIDGE: MAILLART AND AMMANN

Wilhelm Ritter (he dropped the first name very early) had been Culmann's best student. Culmann's lectures, while inspiring, were often unclear, and it was to Ritter (Fig. 7) that his fellow students looked for help in understanding their professor. After graduation, Ritter spent 4 years as Culmann's assistant, proving to be not only a gifted scholar, but also a brilliant teacher. When in 1873, the new Polytechnical School in Riga, Latvia (founded 1862), asked Culmann to recommend someone for the chair in structural engineering, he urged them to take Ritter, who became a full professor there at the age of 26. Following Culmann's death, Ritter was called back to Zurich, where in 1882 he took over the chair of structural engineering and bridge design.[17] Ritter revised and simplified Culmann's approach in a series of books on graphic statics and articles and lectures on design.

Ritter was a teacher whose personality and professional ideas had a profound influence on a generation of Swiss engineers. He was not an aggressive self-promoter. Sensitive to others, he was never known to talk against anyone behind their back. None of his students benefited more than Robert Maillart, and on none of them did Ritter make a more lasting impression. His influence came in two ways: first, through a series of courses taught to juniors and seniors in civil engineering, and, second, through his role as a bridge consultant to three public agencies for which Maillart was to design the early works in which he incorporated his first revolutionary ideas.

As an educator, nurturing students for only a fraction of their lives, Ritter provided an essential link between his student's inborn talents and their future careers. As a teacher, he communicated the recent tradition of his country and of his profession. As a scholar, he took scientific formulations and

Figure 7. Wilhelm Ritter (1847–1906), Professor of Civil Engineering at the Swiss Federal Polytechnical Institute in Zurich; teacher of Robert Maillart. (*Source:* Eidgenossisches Polytechnikum, Festschrift I)

shaped them into clear ideas to reveal better their design potential.

He stood aside and let the students pass on. He did not become in any way competitive by having a design office or domineering by having a design ideology. He was an interpreter of technical events: to his students through his lectures, to the profession through his writings, and to public officials through his detailed consultations that led to Swiss codes for metal structures and works of reinforced concrete.[18]

A strong argument can be made for the judgment that the two greatest bridge designers of the twentieth century were Maillart, using concrete, and Othmar Ammann (1879–1965), using steel (for New York's largest bridges: the George Washington, the Bayonne Arch, the Bronx-Whitestone, and the Verazzano among others). Both had the same professor for bridge design: Wilhelm Ritter. Ritter's name is nearly forgotten, but he touched students of whom Maillart and Ammann are only the most spectacular examples.

RITTER AND THE DESIGN VIEW

To understand the basis for Maillart's education, we need some insight into Ritter's ideas, particularly as contrasted with current ideas in Germany. In 1892, Ritter responded to the German professor, Franz Engesser, who had argued against the full-scale load test for small bridges (driving heavy trucks over newly built bridges to observe their performance) on the grounds that it was more economical and just as reliable to calculate the results mathematically.[19] Ritter's detailed defense of what had become the common Swiss practice of load testing contrasted a Swiss position with a German one: the full-scale field test versus purely mathematical studies. In a broader sense, Ritter reflected a pragmatic, design-oriented attitude as opposed to a more theoretical and applied scientist approach. The Swiss tended to be more open to visual demonstrations of performance.

Maillart accepted Ritter's viewpoint that public works set in a difficult environment are always built with uncertainty. There was no way in the late nineteenth century to predict mathematically the full response of a public structure to its loads. In spite of many new mathematical theories, detailed textbooks, and immense computer power, the same condition exists in the late twentieth century. The validity of any work rests, Ritter emphasized, with "the probing expert" who must give "a reliable judgment"; in short, it always rests finally on the judgment of a person about an existing structure and not on the solution to an equation.

Unlike Culmann, Ritter did not have extensive field experience; his early brilliance led him too soon into a professor's chair for that. But he put high value on the experience he gained as a consultant in the use of load tests, which would play a central role in Maillart's career. Ritter's defense of such field experiences, against German objections, allowed structures to be built that could not be done in Germany in the early twentieth century and for which complex and so-called more rigorous analyses would have obscured the design potential. As a consultant, Ritter could not provide a satisfactory mathematical analysis for Maillart's first major design, the Zuoz Bridge of 1901. But Ritter did direct and interpret the full-scale load test, which demonstrated the validity of Maillart's simple calculations for that structure.

Ritter continued Culmann's effort to widen the engineer's horizons. In a report and in lectures arising from a trip to the United States in 1893, Ritter broadly reviewed forms and new details, and gave a relatively complete technical picture of a few selected bridges.[20] This wide visual variety of solutions to what is essentially the same set of problems is just the combination of insights that most intrigues the design-oriented, as opposed to the analytically oriented, student. Unlike the vast majority of engineers at this time, Ritter did not hesitate to introduce aesthetic judgments as, for example, in describing the high bridge built in 1888–9 over the Mississippi River at St. Paul. "The structure, in spite of its extraordinary size, makes a rather insipid impression; it leads us to realize that aesthetic ideas must have been completely neglected in favor of some utilitarian principles."[21]

As every bridge designer knows, however, good overall form means nothing if the details are bad: All the pieces must fit together and none must be structurally weak. To the watchmaking Swiss, details are a critical part of design. Ritter devoted about one-third of his report on the trip overseas to a detailed review of joints, connections, eyebars, and rivets. Many of his drawings of details are refined and Ritter did not hesitate to criticize other details when he found them to be ugly. As illustrated in a pioneering article on bridge design, Ritter taught structural theory in a simple, elegant, and practical way.[22] He used a minimum of algebraic analysis, which he presented within the context of its design implications partly drawn from his experience in the United States. Ritter had seen in the United States the creative results of a design tradition based on extensive field experience and sound academic training.

Maillart's class notes of 1893 and 1894 are full of drawings and diagrams illustrating Ritter's ideas. They also show Maillart's growing enthusiasm for structural design in general and for bridges in particular. On one page of his notes, he drew a stiffened wooden-arch bridge, a form also featured in Ritter's report on American bridges; underneath it he wrote "a marvelous bridge."[23]

At the time Maillart graduated from the ETH in March 1894, he was a serious-looking 22-year-old: about 5'9", slightly built, with a light mustache, prominent nose, and a high forehead, indicating an already receding hairline (Fig. 8). His myopic eyes were deep-set and intense. The pince-nez he began to wear shortly after finishing school signaled his conservative taste. Maillart's first job was working for a railroad designer in Bern. His education gave him a solid scientific basis for structural engineering, but his close contact with Wilhelm Ritter had made him suspicious of dogmatic theory and provided a strong impetus for design innovation.

Stone Versus Concrete
Zurich, 1894–1899

THE NEW MATERIAL AND THE TRADITION OF MASS

During the first 5 years of Maillart's career, reinforced concrete came from being a little-used novelty to a major building material throughout the western world. This evolution was due largely to three pioneers: a French gardener-inventor Joseph Monier (1823–1906), a French builder-designer François Hennebique (1843–1921), and a German engineer G. A. Wayss (1851–1917).

Monier took out numerous patents on iron-bar and wire-mesh, reinforced-concrete shells, beams, and columns. In the late 1880s, Wayss bought these patents, founded a business based on designing and building reinforced-concrete structures, and began a testing program that lead to standardized formulas as a basis for design. The Wayss and Freytag firm became a leader in concrete structures through-