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Frank Lloyd Wright and the concrete slab and column

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This paper traces the development of Frank Lloyd Wright's ideas on the place of the concrete column and slab in architecture. It deals with his first employment of the slab at Unity Temple (Oak Park, 1904) and his use of the form in residential projects during the next few years. It surveys American literature on concrete construction and briefly analyses the contribution of Claude A.P. Turner and the employment of the Turner system in two Chicago buildings that Wright would have known. It discusses his project for the San Francisco Call (1912) and the use of the Barton system in the Richland Center warehouse for A.D. German (1915). It further discusses his first probable knowledge of the more sophisticated concrete slabs of Maillart, published in 1926, and of Maillart's invention of a proto lily-pad capital. This capital is also to be seen in Wright's champagne glass designed for Leerdam (1930) and in his project for the Salem Capitol Journal of 1931. Finally it is argued that the much admired lily-pad columns at the Johnson Wax office building (Racine, 1937–39) are really a series of three-hinged bents rather than shell construction.

In his eloquent narrative, 'Designing Unity Temple', Frank Lloyd Wright indicates that the building had to be made of concrete for reasons of economy. He then asks the rhetorical question: 'What had concrete to offer as a cover shelter? The concrete slab – of course. The reinforced slab. Nothing else if the building was to be thoroughbred, meaning built in character out of one material.'[1] The difficulty with his account is that it was written approximately 25 years after the event. And, as so frequently occurs in the fascinating but maddening pages of *An Autobiography*, he omits or distorts some of the major considerations affecting the technology of the building. It was the first concrete slab that Wright actually built, but he had been interested in the material for some time, though not in slab form. It is necessary to begin with a review of concrete construction at the time Wright entered practice.

Like most progressive young architects around the turn of the century, Wright was fascinated by reinforced concrete. No one was sure what could be achieved with the new material, but it was clear that the possibilities were enormous. Depending upon its use, it might combine the tensile strength of steel and the compressive strength of stone. Hence the field of concrete construction was filled with inventors who sought to capitalise on its possibilities. The intensity of the interest is suggested by the treatment of concrete in Frank Kidder's *Architect and Builder's Pocket Book* between 1885 and 1905. This volume, first published in 1884, was for two generations probably the most common structural reference for

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American architects. In 1885 Kidder's manual featured one page on concrete. The author regarded it as a good material for foundations. Twenty years later in his 1905 edition Frank Kidder needed 67 pages to discuss various kinds of beams, slabs, frames and types of reinforcement. Whether or not Wright knew Kidder's work we cannot positively say – but it would have been surprising if he didn't. Writing in 1928, a few years prior to the composition of *An Autobiography*, he stated that the physical properties of concrete were well understood, but that 'Aesthetically it has neither song nor story.'[2] He added that it was essentially a conglomerate, and that cement, the binding material, was in itself characterless. 'As a material,' he wrote,

'it is its misfortune to project as wooden beams, travel molded as cornices. Yet it will faithfully hang as a slab, stand delicately perforated like a Persian faience screen or lie low and heavily in mass upon the ground. Again, unluckily, it will stand up and take the form (and texture too) of wooden posts and planks. It is supine, and sits as the fool, whose matrix receives it, will.'[3]

The language reveals something of Wright's scepticism about the structural uses of concrete up to that time. It may also reflect his own experience. Here we should note Wright's attitude towards technology. With his life-long interest in nature as the basis of organic architecture, Wright was unquestionably a Romantic. He depended on intuition and feeling, and too often discounted the rational approach to creative building. Fortunately during the first part of his career he was able to call upon the capable services of Paul Mueller in the erection of his large structures: the Larkin Building (Buffalo, 1904), Unity Temple (Oak Park, 1904), Midway Gardens (Chicago, 1914) and the Hotel (Tokyo, 1916–22). Mueller should receive substantial credit for the success of these structures.

Not only did Wright's demands on his materials often exceed their physical properties, he also 'pressed the envelope' in terms of structural form. Throughout his career his demands generally exceeded the known capabilities of his materials. This was true whether he was designing glassware for Leerdam or a structural element in a building. He always wanted to be on the frontier. At the same time he was extremely alert to any new developments in building. As a consequence of this combination of attitudes his structures showed remarkably few failures but a good many deflections.[4] In the passage just quoted, Wright observed that concrete could unfortunately take the form (and texture) of wooden posts and planks. It was such a post-and-beam system that Wright employed in the important but problematical project for a Village Bank, first published in *The Brickbuilder* in August 1901 (Fig. 1). This project has a curious history. Grant Manson found a small pen-rendered perspective of the identical design labelled 'Study for Concrete Monolithic Bank, 1894'. In the published version, however, Wright declared that 'The building is constructed entirely of brick', and added, 'The design makes use of the structural feature of the piers carrying ceiling beams of the long span as the decorative element providing the enrichment of the façades . . .'[5] The

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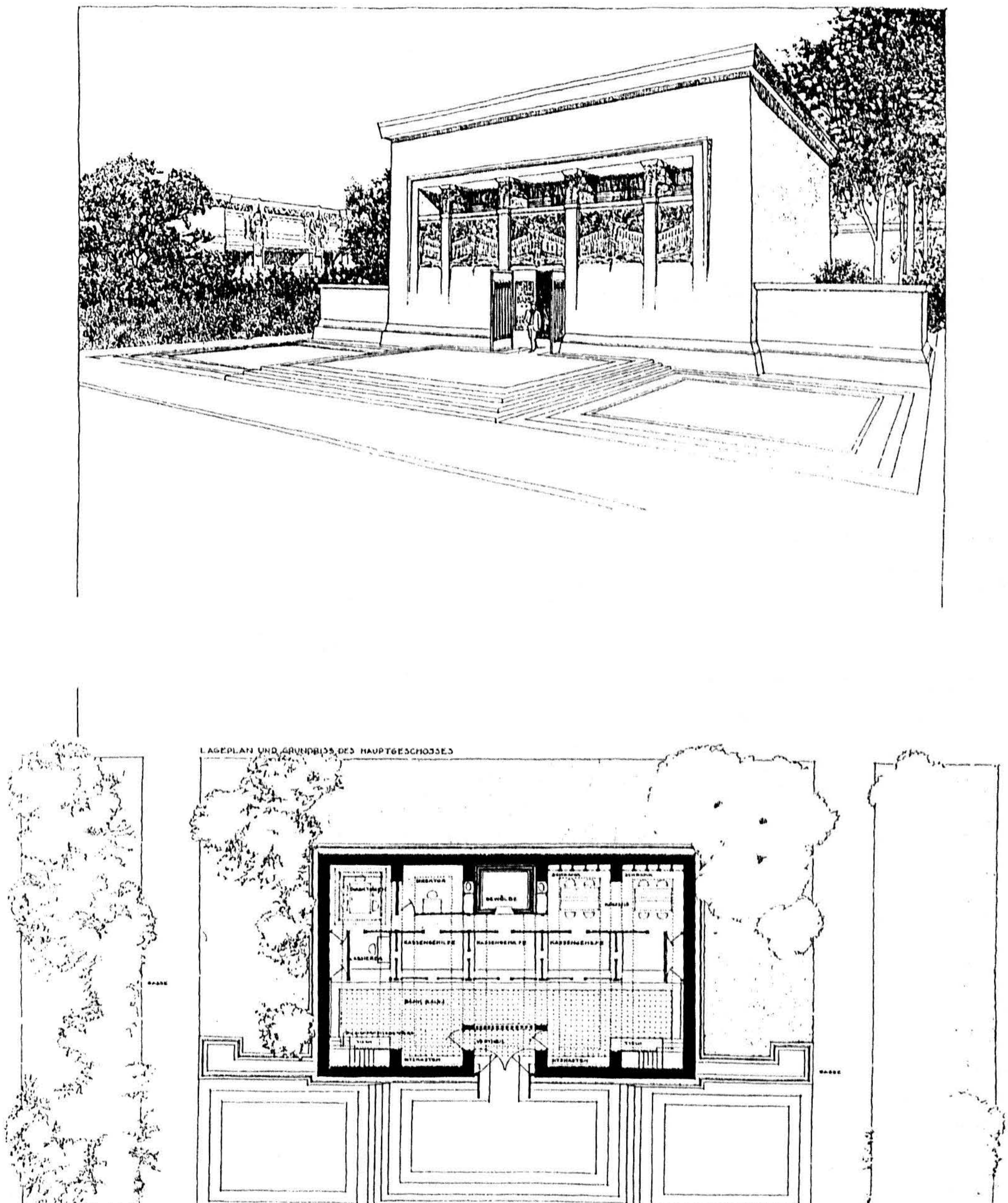

Figure 1. Village Bank project, 1894. (source: Frank Lloyd Wright, Ausgeführte Bauten, und Entwurfe, Berlin, 1910)

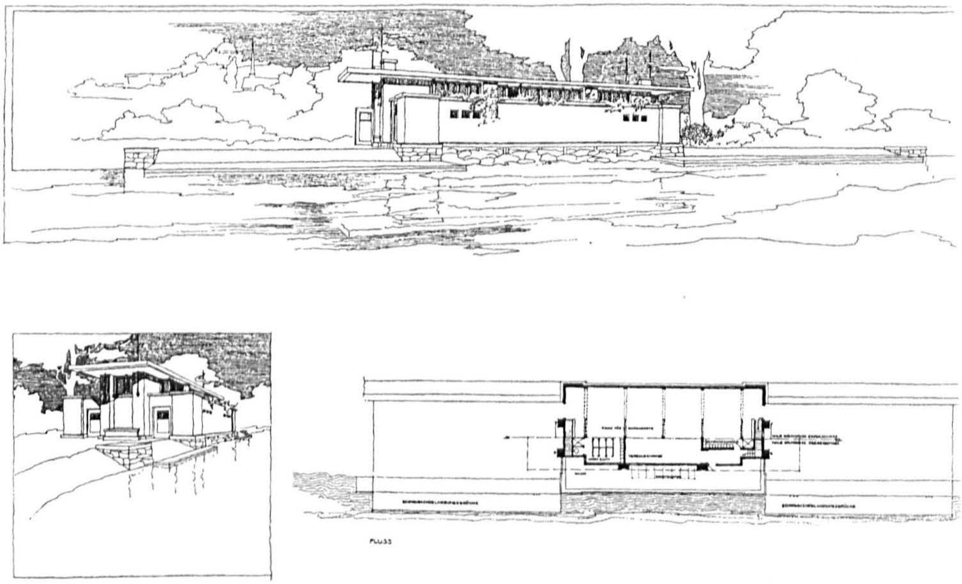

Figure 2. Yahara Boat Club project, 1905. (source: Frank Lloyd Wright, Ausgeführte Bauten, und Entwurfe, Berlin, 1910)

ceiling beams would presumably have been of concrete. In terms of the building technology of the day, the structure would not have been anything unusual. It appears, then, that the original project was for concrete, probably not reinforced, but when Wright was offered an opportunity for publication, he saw that it could be done in brick. When he again published it as plate XI in the *Ausgeführte Bauten und Entwürfe* (E. Wasmuth, Berlin, 1910) he reverted to the original designation. The edifice would have been richly decorated, but in form it would have been, as Grant Manson remarked, 'an uncompromising cube'.

In the years immediately after 1900 Wright moved away from the post-and-beam system of the Village Bank Project and began to concentrate on cantilevered slabs, many of them in concrete. The reasons for this new direction are unclear. One is tempted to speculate on the importance of the lost pavilion for the Universal Portland Cement Company at the Pan-American Exposition in Buffalo of 1901. Presumably the company would have wanted a structure that displayed the capabilities of its products. Hitchcock believed that the pavilion resembled the unbuilt Yahara Boat Club project of 1905 (Fig. 2). The correspondence makes it perfectly clear that Wright visualised a building executed in frame and plaster.[6] At some later date he decided that the boat club's massing and daring cantilever were more suitable for construction in concrete, and publicly pronounced it concrete in the 1931 European exhibition of his work. Indeed, it is difficult to see how the cantilevered slab would have endured in any other material.

Wright's first concrete slab of substantial size came at Unity Temple (Oak Park, 1904), one of the most important buildings of his entire career (Fig. 3). Originally a solution in brick was proposed, but that material was too expensive. In the *Ausgeführte Bauten* of 1911, the only contemporary account by Wright of the technology of the building, he states that 'the roofs are simple reinforced concrete slabs, waterproofed'.[7] This assertion is not strictly true. The auditorium is actually top-lit by a steel lattice, which contains panels of leaded glass (Fig. 4). This lattice is really a continuation of the four slabs that are cantilevered out from the corner piers. The whole structure fits together as neatly as a jigsaw puzzle. The slabs sail over the exterior walls with a margin of about 2 in (50 mm) – a perfectly clear statement that the exterior walls of the building are entirely separate from the roof. The opening is not visible in any drawing or model, but it is of the utmost importance as a subtle but forceful expression of the cantilever, a structural principle that Wright was to use extensively in the next few years.[8]

In one sense there was nothing unusual about Wright's slabs of 1904. By that year it was generally known that the concrete slab responded to beam theory. There is a substantial literature that makes this point clear. F.E. Turneaure and E.R. Maurer in their authoritative *Principles of Reinforced Concrete Construction* (New York, 1905) held that the flat slab supported on four sides was essentially a special case of the beam.

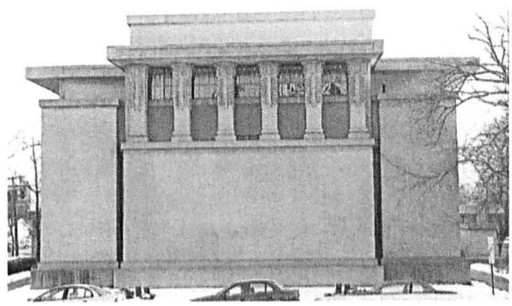

Figure 3. Unity Temple. (photograph by Sidney Robinson)

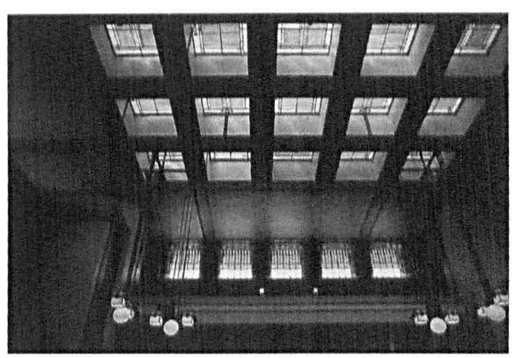

Figure 4. Ceiling, Unity Temple. (photograph by Allen Cunningham)

The authors were aware that the shearing stresses were dangerous only in exceptional circumstances, such as when a heavy load was applied close to a support. As one studies this literature of 1900–1910 one is impressed both with what was known and with the large areas of ignorance. There was, for example, no generally accepted definition of the word 'modulus'. Several authors were aware that there was a fatigue limit in the metal reinforcement, but there was a good deal of doubt as to how that limit could be figured. Nonetheless, there was enough knowledge that Wright (and

Mueller) could safely pour their slabs and calculate their strength. What was unusual was the use of a building element devised as a floor to be a roof. Frederick W. Taylor and Sanford E. Thompson in the second edition of *Concrete: Plain and Reinforced* (New York, 1904 and 1909) listed no less than 37 types of slab reinforcement, many of them patented. Most of these systems were for floor slabs. Wright, however, was not interested in floors in Unity Temple. He wanted slabs that could be cantilevered outwards from the great corner piers, over the walls and, on the interior, bound to the steel lattice that contained his leaded glass. Wright's slabs really held up nothing except themselves. Their use was a remarkable architectural and technological innovation for 1904. As Wright later noted, the slabs had to be reinforced, and the type of reinforcement must have been a substantial question for Wright and Mueller. Wright gave Mueller full credit:

'It is exciting to him to rescue ideas, to participate in creation. And together we overcame difficulty after difficulty in the field, where an architect's education is never finished.'[9]

Exactly what kind of slabs did Wright and Mueller build at Unity Temple? The answer to this question is rather startling. A recent structural survey found that the reinforcing bars ran perpendicular to the edge of the overhang, and turned up approximately 6 in (150 mm) from the outer edge. Some of these bars are 1 in in diameter, and are twisted, square reinforcing bars, while others appear to be 0.5 in diameter, smooth round bars. All bars are irregularly spaced from 8 to 16 in (200–400 mm) on centre. They are of varying lengths, and extend from 2 to 5 ft (0.6–1.5 m) from the fascia. These bars appear to turn up into the slab or edge beam along the fascia, but this point is not entirely clear. There are two round bars running parallel with the fascia, located approximately 5 and 10 in (125 and 250 mm) from the edge of the overhang. There is approximately 2.5 in (60 mm) of cover below the bars. The reinforcing bars running perpendicular to the fascia apparently hook over these two bars, and turn up into the slab or the edge beam. In short, the reinforcing in the slab looks very much like an ad hoc solution. Where there seemed to be a need for a rebar, Wright and Mueller put it in. The surveying engineers found a good deal of delamination in the structure. That it has endured as well as it has is something of a miracle. After almost a century there is remarkably little deflection visible in the slab.[10]

Wright's next use of the concrete slab was in his third project for the *Ladies Home Journal* in April 1907, and was entitled 'A Fireproof House for $5000' (Fig. 5). In his description of the building he wrote:

'The walls, floors and roof of this house are a monolithic casting, formed in the usual manner by a wooden false work, the chimney in the centre carrying, like a huge post, the central load of floor and roof construction. Floors and roof are reinforced concrete slabs approximately five inches thick if gravel concrete is used. The roof slab overhangs to protect the walls from sun and the top is waterproofed with a tar and gravel roofing

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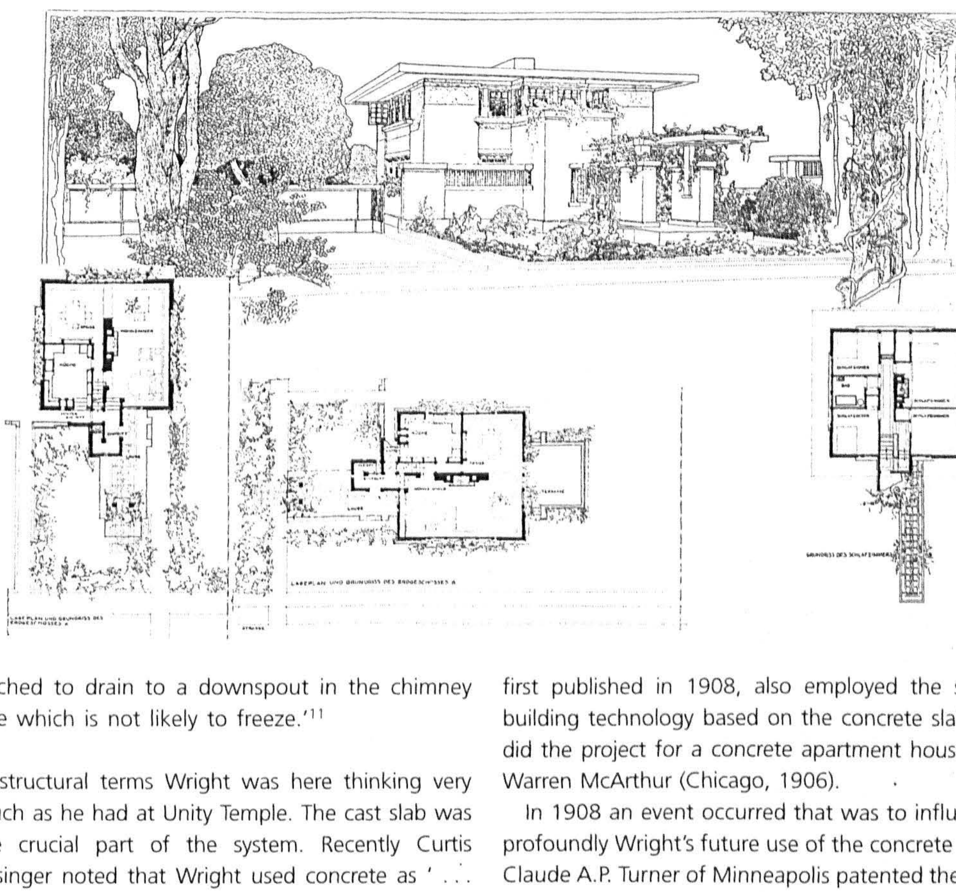

Figure 5. Fireproof house for Ladies Home Journal, 1907. (source: Ausgeführte Bauten)

pitched to drain to a downspout in the chimney flue which is not likely to freeze.'[11]

In structural terms Wright was here thinking very much as he had at Unity Temple. The cast slab was the crucial part of the system. Recently Curtis Besinger noted that Wright used concrete as ' . . . massive planar elements and piers that enfolded and defined the spaces. Enclosure was completed by glass elements inserted between the concrete elements'.[12] As will be noted, Wright's system was dramatically opposed to that of Auguste Perret, the other great virtuoso in reinforced concrete of his generation. The unbuilt studio house for Richard Bock, first published in 1908, also employed the same building technology based on the concrete slab, as did the project for a concrete apartment house for Warren McArthur (Chicago, 1906).

In 1908 an event occurred that was to influence profoundly Wright's future use of the concrete slab. Claude A.P. Turner of Minneapolis patented the first mature system of column and slab framing. To thinking engineers it had long been obvious that the whole apparatus of under-girders and beams could be dispensed with if the column and slab could be designed as a unit. Turner accomplished this objective by combining concentric, radial, and continuous multiple-way reinforcement with a flared capital whose purpose was to reduce the shearing stress at the perimeter of the column. This capital, which was frequently accompanied by a drop panel, was mushroom shaped and gave its name to the system. Though Turner's patents were finally thrown out of court and those of Orlando W. Norcross were upheld, the Turner system was quickly adopted by architects all over the country. It was particularly useful for designers who were confronted with the problems of industrial buildings and of multistorey structures.

Thus Turner made a major contribution to the development of the slab. Professor Emory Kemp remarks:

'His development of the two-way slab moved concrete from a material imitating timber, masonry, and even iron structures into a field where it was unchallenged in providing moments and torsion in two directions.'[13]

The elastic solution involves a fourth-order partial differential equation, and it is highly unlikely that Wright ever understood the two-way bending of a flat slab floor. Nonetheless, he was an architect with an amazing structural intuition, and it must have been clear to him that something remarkable had happened in the realm of concrete. At the minimum he probably understood that the new and improved type of slab construction dictated columns with a new kind of capital to take the shear that they generated.

That Wright was interested in the new type of slab construction during the decade prior to the First World War is highly probable. That he knew of the new type of slab developed by Turner cannot be proven – but it would have been surprising if he had been ignorant. His career is full of instances where he was silent about his professional obligations. For example, he never mentioned his conflict with William Nelson, an inventor who developed a system of concrete blocks much like the textile blocks that Wright developed for his California houses of the 1920s. Nelson confronted Wright with claims of patent infringement and, says Robert L. Sweeney, 'Wright's response was circumspect at best . . . '[14] In much the same way he never acknowledged the impact of the Viennese Secession on his decorative designs for Midway Gardens.

Because the Turner slab and its supporting column were to be profoundly influential on Wright, let us look at two pre-war buildings that might well have been known by Wright. The first is the Dwight Building by Schmidt, Garden and Martin (Chicago, 1911). H. Allen Brooks writes of its ' . . . structural logic, predominant horizontality and disdain for historicism . . . ',[15] and correctly notes that for Hugh Garden, the building's designer, it was the end of a line. Yet Brooks nowhere observes that the Dwight Building was framed in reinforced concrete on a flat slab system (Figs 6–9). Perhaps this is not surprising. On the basis of experimentation with my former colleagues in Ann Arbor I shall argue that there is no way of telling how the building goes together on the basis of exterior photographs alone. The other structure is the Lakeside Press for R.R. Donnelly and Sons Company of 1912 by Howard Van Doren Shaw (Figs 10 and 11). As the photograph indicates, the

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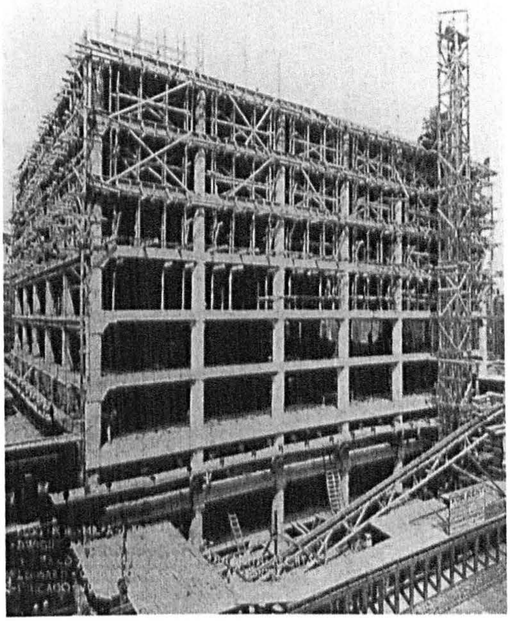

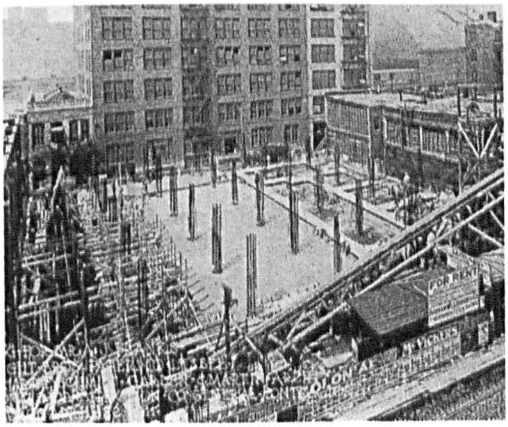

Figure 6. The Dwight Building, Chicago, 1910–11. Schmidt, Garden, and Martin. This photograph, and its companions, are taken from Built by the Leonard Construction Co. (Chicago, 1917). I have seen only a single copy of this publication. It is in the architectural library of the University of Michigan.

Figure 7. The Dwight Building under construction.

Figure 8. The Dwight Building under construction.

large interior is spacious and well lit – and it can safely accommodate heavy rolls of paper and even heavier presses. In passing, the utility of the slab for printing establishments is worth noting. It would take very heavy loads and was almost vibrationless. Garden was for a time a member of the Prairie School, and knew Wright well. Shaw was almost Wright's exact contemporary, and though he was at odds with Wright architecturally, the two men liked and respected each other. Nonetheless we would have to admit that neither Garden nor Shaw, who were quite different architects, moved very far in giving the flat slab a distinctive architectural expression. In a certain sense structure was

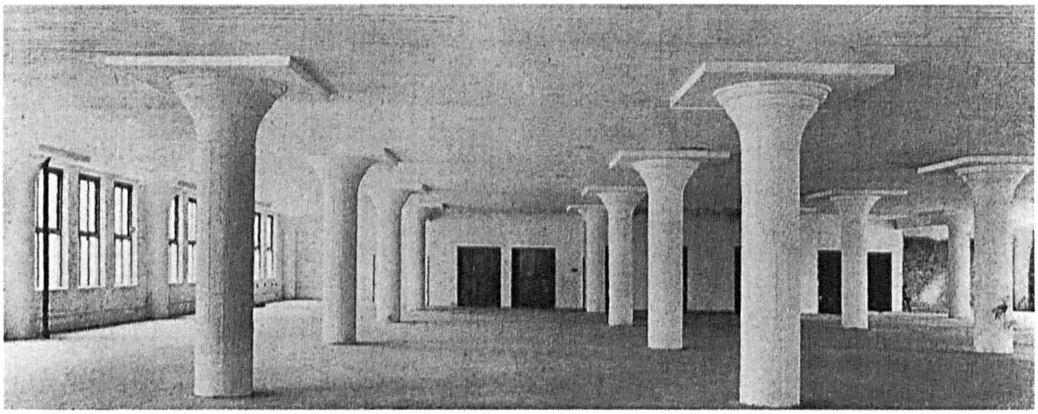

Figure 9. The interior of the Dwight Building on completion.

irrelevant to design in these buildings. Architecture was something that was draped over a system of columns and slabs. It remains to be noted that both buildings were erected by the Leonard Construction Company, the Chicago experts in reinforced concrete construction.

Wright's first large project in the new type of slab is the interesting but structurally improbable project for the *San Francisco Call* of 1912. The model and two plans for this building were published in *The Work of Frank Lloyd Wright, Wendingen* (republished by Horizon Press, 1965) (Figs 12 and 13). It would have been a structure about 20–21 storeys in height – by no means an impossibility with the building technology available at the time. The plans are clearly marked 'Reinforced Concrete Skyscraper – slab construction'. While these plans are not dimensioned, the building could not have been more than about 30 ft (9 m) wide at the utmost. If we take a dimension of 8 ft (2.4 m) for the staircases and grant a possible extension of the slab bay to 30 ft, this conclusion seems inevitable. If built, the structure would have been one of the most attenuated skyscrapers imaginable.

In an article for the *Concrete Engineers Handbook* of Hood, Johnson and Hollister (New York, 1918), Professor Walter C. Edge analysed four different classes of slab and seven patented systems, the majority of which were operated under licence from the Flat Slab Patents Company of Chicago, a creation of Clifton S. Leonard. In 1915 Frank Lloyd Wright was confronted with a commission in which the use of one of these patented systems was mandatory. This was the A.D. German Warehouse in Richland Center, Wisconsin (Figs 14 and 15). It was to house the business of Albert D. German, a prosperous dealer in flour, feed and cement in the town where Wright had been born.[16] In addition to the space for the storage of wholesale goods the programme included a small teahouse restaurant, specialised retail shops, a wholesale outlet store,

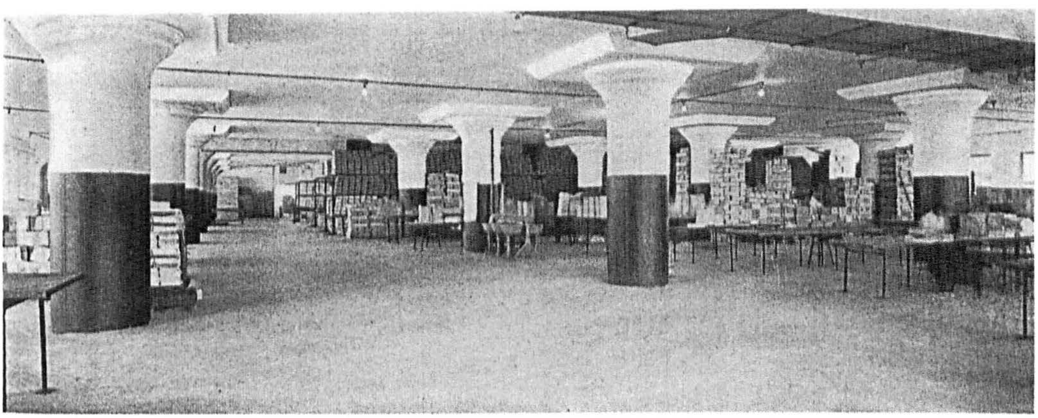

Figure 10. Interior of the Lakeside Press.

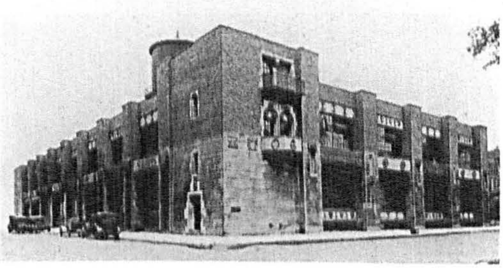

Figure 11. The Lakeside Press, Chicago, 1912. Howard Van Doren Shaw.

and a gallery for local and regional artists – rather an ambitious project for a small town warehouse. Nonetheless the core of the building was the warehouse space, and for it Wright had to choose one of the patented flat slab systems. To do otherwise would have been to neglect the benefits of the latest building technology and perhaps risk structural failure. For Wright this was simply inconceivable. We can assume that he was familiar with all the flat slab systems. In this instance he chose the Barton or Spider Web System. Why?

There are two distinct possibilities, but no testimony from the architect himself. The first is the organic reference. In view of the importance of abstraction from the natural world in Wright's organic design, it is entirely possible that a system based on a spider web might have appealed to him. The second possibility lies in the character of the system itself. According to Edge, the Barton system was similar to other flat slab systems as to the arrangement of columns, column heads, and drop panels, but differed radically in the type of reinforcement. Without becoming overly technical, we can say that its distinguishing feature was that the reinforcing web ran through the entire apparatus of columns, capitals, drop panels, and floors so that the whole thing was conceived as a single unit. It was ' . . . a four-way system in which all the major slab reinforcement units of negative (column head) and positive (slab centre) steel, lap past each other so as to provide steel at top and bottom of the slab in the region of shifting inflection.'[17] The patent

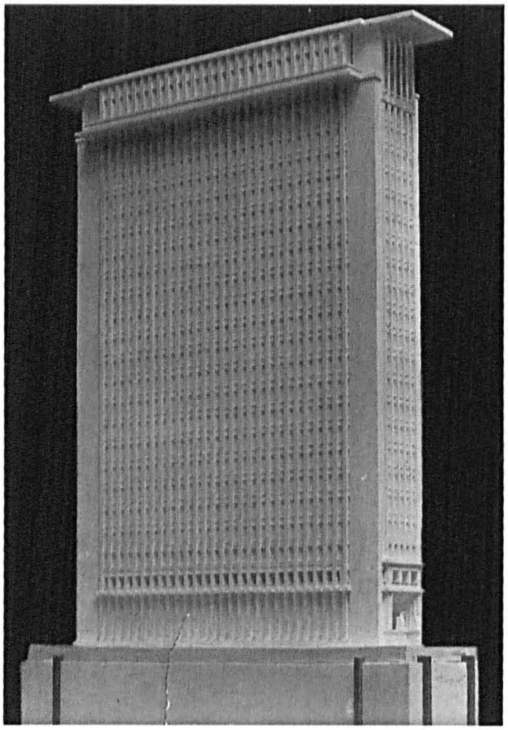

Figure 12. San Francisco Call project, 1912. (source: Frank Lloyd Wright Archives)

office drawings for the Barton system make clear that a series of ingeniously designed metal connections is the outstanding feature (Fig. 16). The Barton engineers believed that the methods of arriving at bending moments advocated by the American Society of Civil Engineers were the most mathematically correct but that the coefficients were needlessly conservative. The Chicago code was the most satisfactory for practical use. With the possible exception of the cantilever flat slab, the Barton system was both the strongest and the most elegant structural method available to Wright for his warehouse.[18]

An examination of the system as it exists today in the A.D. German warehouse shows that Wright's columns here are distinguished from those of his contemporaries in two principal ways. In the first place he gave them a square plan. As so frequently with Wright, there may have been at least two reasons for this decision. His fondness for the square is well known. But the decision also makes sense in terms of the concrete building technology available to him in Richland Center in 1915. The town was (and is) in a rural part of Wisconsin. Square forms would have been easier for the local carpenters to build than the more commonly used circular forms. Accounts of the building process make clear that the warehouse was put up by an eight-man crew with a chain-driven mixer. In this situation a sophisticated building technology was simply impossible.[19]

In the second place, he designed a column head that flares dramatically (Figs 17 and 18). That he intended his capitals to be visible is clear from the original rendering as published in *Wendingen*. Those at the entrance to the building were ornamented with a motif closely related to that which was used on the upper storeys of the exterior. The flaring form distributes the shear inherent in the system in a manner that anticipates the more elegant solutions that Swiss designers were to achieve in the late 1920s. The result is, of course, radically different from the conventional use of the Barton system as seen in a contemporary building for the Stewart Warner Speedometer Corporation in Chicago (Fig. 19). The drawings in the Barton patent of 1915 suggested

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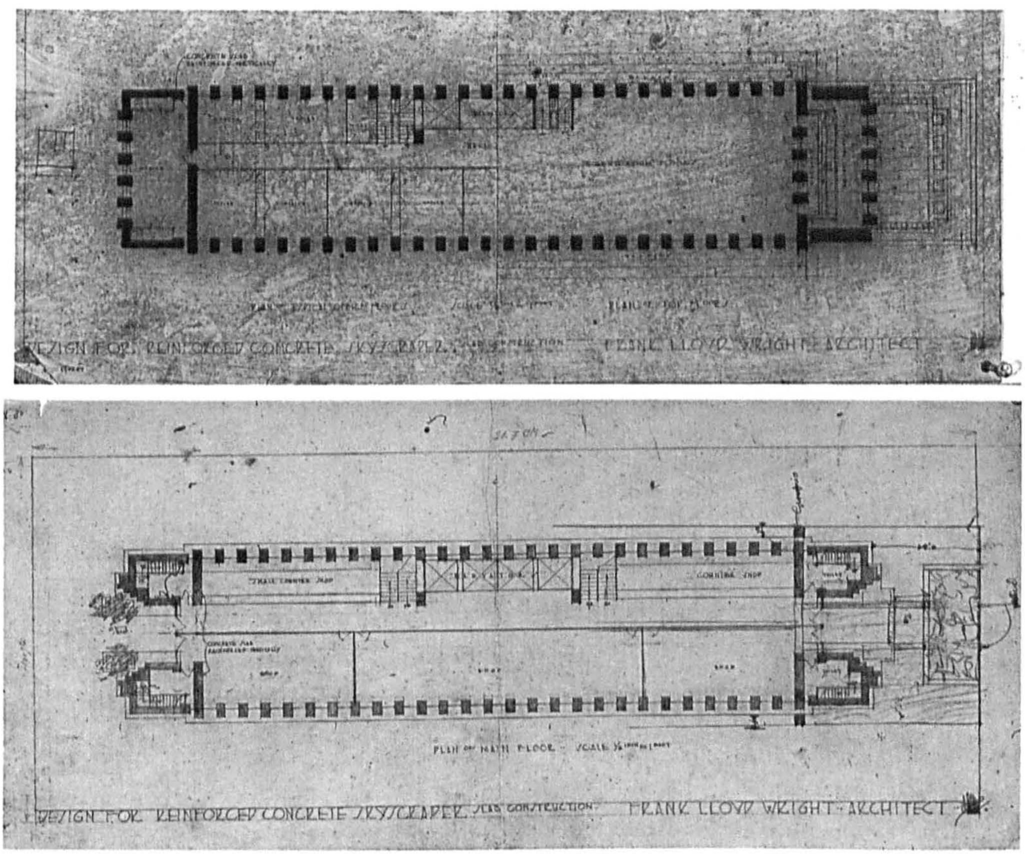


Figure 13. San Francisco Call project plan. (source: Frank Lloyd Wright Archives)

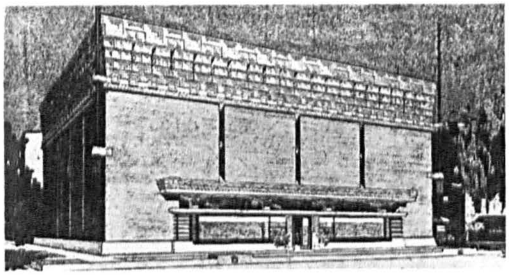
an octagonal form, but the final choice was of course up to the individual designer.

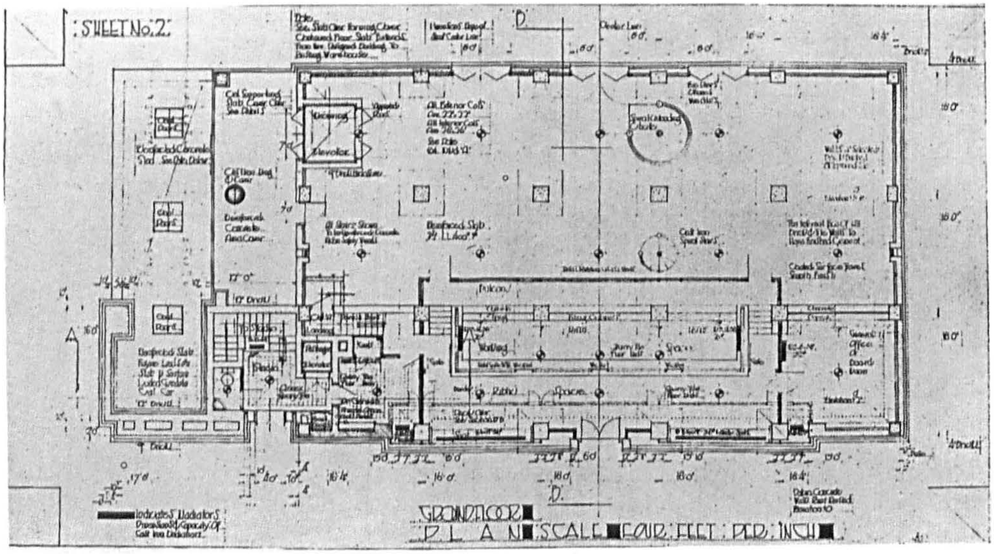
Here, then, is Wright's first realised project involving the new type of slab and column. Whether or not he was satisfied with the entire building is hard to say. In the *Wendingen* publication of 1926, for which Wright supplied drawings and photographs, there were three exterior views and a ground plan but no text or description. Up to the present time I am not aware of any published illustrations of the interior. I am inclined to believe that there is a very good reason for this situation. If Wright had published it, the space would not have looked very different from most other warehouses of the period; in fact, it would have appeared less well lit than many. And it would have been clear that he was

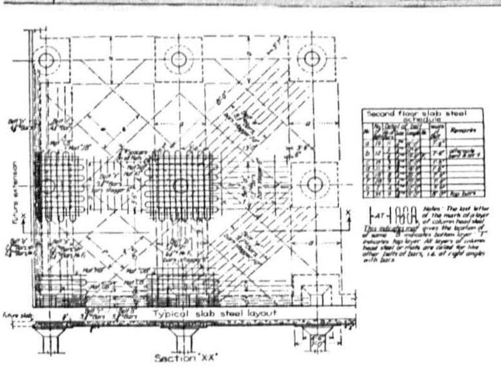
Figure 14. A.D. German Warehouse, Richland Center, Wisconsin. Frank Lloyd Wright, 1915. (source: Wendingen)

Figure 15. A.D. German Warehouse, ground floor plan, (source: Wendingen)

Figure 16. Barton Spider WebSystem Diagram, (patent drawing)







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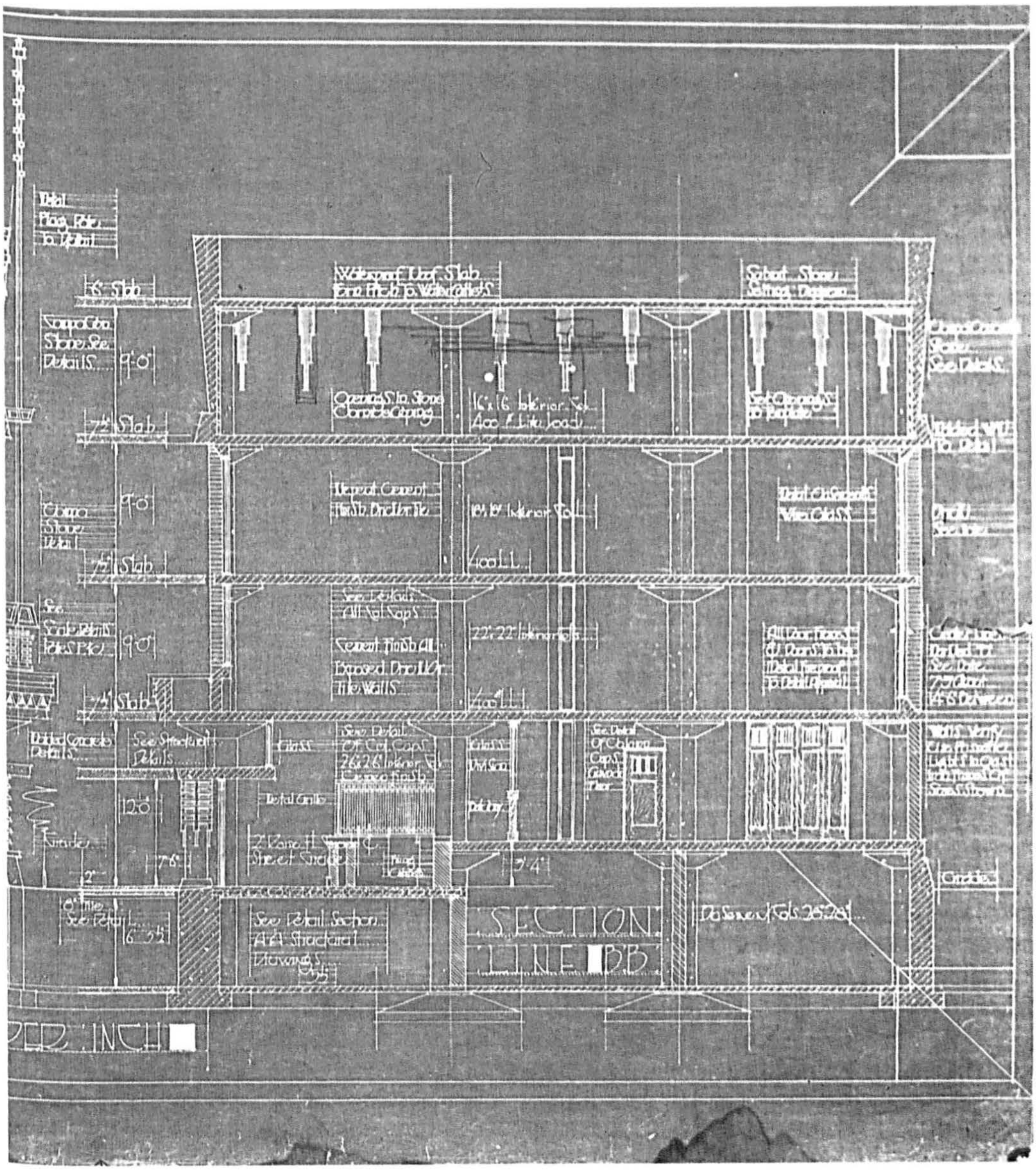


Figure 17. A.D. German Warehouse, section, (source: Frank Lloyd Wright Archives)

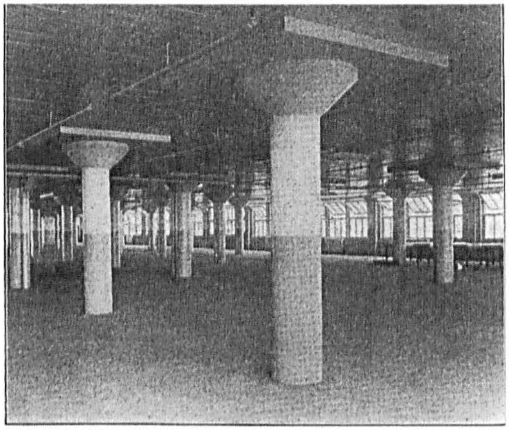


Figure 18. A.D. German Warehouse, interior, (source: Lou Coopey, Richland Center, Wisconsin)

Figure 19. Stewart Warner Speedometer Corporation Building, Chicago, (source: Built by the Leonard Construction Company)

using a structural system not of his own devising – always an unpleasant position for an architect of wilful originality. This might be sufficient cause for the biting language of the 1928 essay on concrete – but there is another even deeper reason. During his entire architectural career of more than 60 years Frank Lloyd Wright was in revolt against the categories of Renaissance architecture. His attacks are so well known that there is no point in quoting them. What has perhaps been insufficiently noted is that, in accordance with his doctrine, he abjured almost entirely all kinds of load-bearing columns in the practice of his first 25 years. One can go through the enormous production of prairie houses without finding anything that passes for a column. One can examine large buildings like the Midway Gardens and the Imperial Hotel without discovering columns. One can even hypothesise that his early interest in cantilevers came about because of his determination to avoid columns. (Donald Hoffmann has put forward this view.) When, however, he was confronted with a client whose warehouse had to contain bags of cement, he confronted a floor load that was very substantial in terms of pounds per square foot. For the first time he had to concentrate on the column rather than the slab.[20]

It is instructive, I think, to contrast Wright's attitude to the column with that of Auguste Perret, the major exponent of traditional French classicism in concrete. As Peter Collins pointed out, Perret began his architecture with an analysis of the nature and function of the column. It was ' . . . the element in his vocabulary to which he attached the most importance.'[21] In another important passage Collins wrote:

'August Perret liked columns, and proliferated them with all the enthusiasm of the architects of the past. It was not only the inherent structural dignity of the column itself which captured his imagination but the powerful emotional effect created by receding ranks of columns, and the optical function fulfilled by such rhythmic sequences in creating an awareness of scale beyond the effective bounds of stereoscopic sight. However much the Renaissance principles of perspective might be outmoded as a means of pictorial representation, the abiding reality of its laws as a means of apprehending spatial relationships seemed to him incontestable, and instead of diminishing or camouflaging his structural supports, he sought every means at his disposal to isolate them in space, and make their rhythm provide the dominant unifying element of his designs.'[22]

If one studies the nave at Perret's great church of Le Raincy of 1925 (Fig. 20), what Perret was driving at is absolutely clear. It is the precise opposite of everything Frank Lloyd Wright stood for.

In 1929 Francis Onderdonk published *The Ferro-Concrete Style*. This volume is a comprehensive but confused summary of everything that had been achieved in reinforced concrete up to that time. We know that Wright was familiar with it because he wrote to the young Swiss architect Werner Moser on 25 July 1929 remarking that ' . . . nearly everything to date is in this book. You ought to have it.'[23] In the same letter he stated his appreciation for the church and tower of the Antoniuskirche in Basel by Karl Moser, Werner's father. These structures are shown on pp. 239–241 of Onderdonk (Figs 21 and 22). It is interesting to note that the vertical supports are square in plan. The design must have been congenial to Wright.

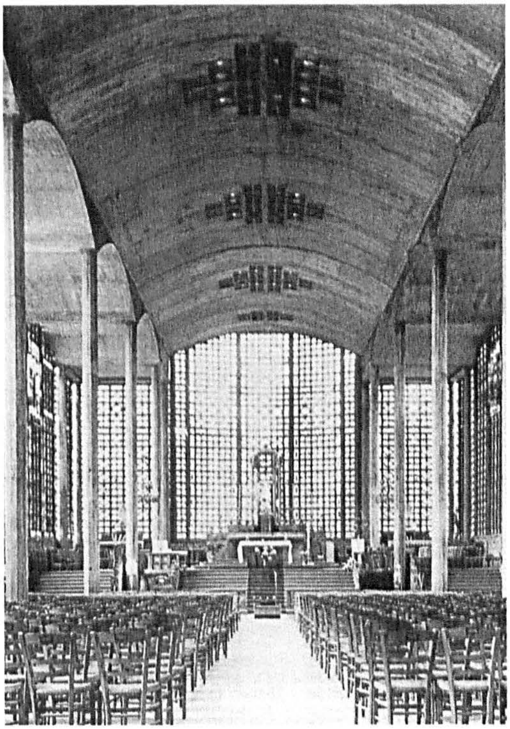
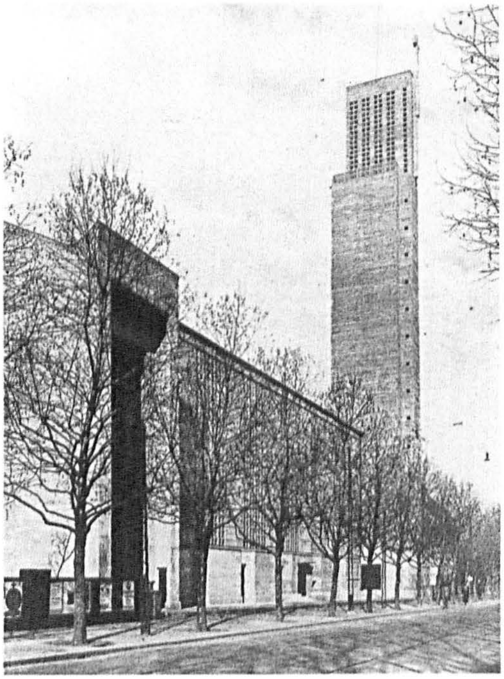


Figure 20. Nave, Notre Dame de Raincy, Auguste Perret, 1924–25

On p. 223 Onderdonk illustrated Maillart's Federal Grain Warehouse of 1910 in Altdorf, with its beautiful capitals and beamless ceiling (Fig. 23). It is hard to escape the conclusion that Wright was familiar with Maillart's improved version of the flat slab by the late 1920s, if not earlier.

He might indeed have known of it through the agency of Moser, who was in his studio 1924–27, and in my view this is highly probable. Maillart had published his comparison of the American slab as developed by Turner and his own more sophisticated version in a paper entitled 'On the develop-



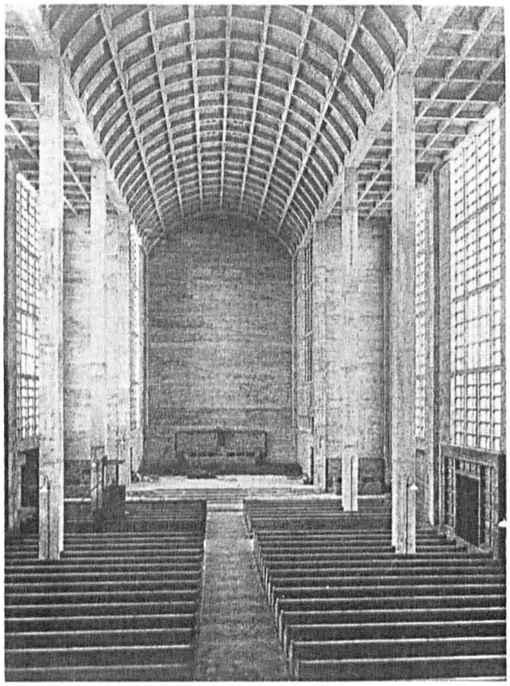


Figure 21. Antoniuskirke, Basle. Karl Moser, 1926. (from Onderdonk, The Ferro-Concrete Style)

Figure 22. Nave of Antoniuskirke. (from Onderdonk, The Ferro-Concrete Style)

ment of the beamless ceiling in Switzerland and America' in the *Schweizerische Bauzeitung* of 22 May 1926. This was the same periodical that, in 1911, had published H.P. Berlage's two important articles on his American journey, that had played a major role in bringing Wright to the attention of European architects. It is probably worthwhile to point out here that in 1926 Wright had almost no architectural work in the office and plenty of time for reading. And in Moser he had a gifted student and lifelong admirer who was extremely familiar with European developments. Maillart had in fact already worked with Moser's father in Switzerland. It can safely be presumed that the younger Moser was familiar with Maillart's achievements in both buildings and bridges.

Let us suppose that the *Schweizerische Bauzeitung* of 22 May 1926 arrived at Taliesin, and that Wright asked the young Moser for a translation. Moser would have scanned it and replied that the piece had been done at the request of the editors to clarify discussion that arose at an exhibition of industrial and engineering structures at the Zurich Kunstgewerbemuseum the preceding February. Apparently a certain number of executed American projects were shown. Issues of priority and the

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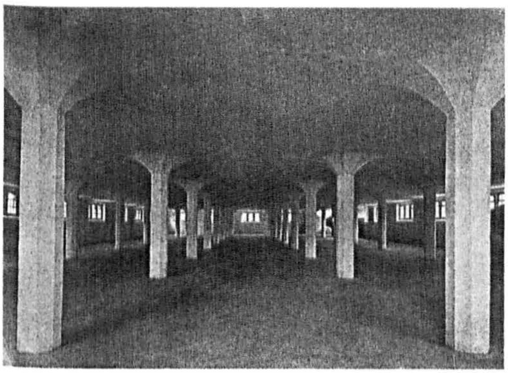

Figure 23. Federal Grain Warehouse, Altdorf, Switzerland, Robert Maillart (from Onderdonk The Ferro-Concrete Style).

ancient argument of beauty versus utility were raised. The editors therefore asked Robert Maillart for an explanatory article, and appended to his essay a series of illustrations which showed structures built according to his designs.

Maillart began by commenting that when concrete first emerged as a possibility for long-span structures the engineer treated it as though it were wood or steel. He conceived of it only in terms of joists, columns, and beams. (In some ways he sounds like Wright.) However, there were possibilities of reinforcing slabs in a crosswise manner that could distribute bending stresses in any direction, not only in the two directions of reinforcement. This situation led Maillart to conduct two remarkable series of tests at Zurich. Those experiments resulted in a knowledge of the fundamental properties of slabs, which Maillart turned to good account. Like the Americans he patented his system, and in the years up to the First World War did a great deal of building throughout Europe. His first building with the beamless floor slab was a warehouse at Giesshubel, Switzerland of 1910. It is still giving good service today. This achievement of Maillart was twofold: he understood the behaviour of the slab more completely than his American contemporaries, and he gave it a more elegant expression. With regard to the first consideration, David Billington has remarked that Walter Lord, the American engineer who made early efforts to analyse the slab, actually measured the wrong things in his experiments, thereby creating great difficulties in the development of a code for concrete construction in the United States.[24] Maillart understood the need to measure deflection in the system as a whole. And every element in the Maillart slab was designed with an elegance far beyond what was customary in America. Maillart's 1926 paper was illustrated with drawings that compared his system with that of the American C.A.P. Turner, whose 1910 publication was his reference. His illustration showed that his slab was both more economical and more refined (Fig. 24). It will be seen that the column capital has a gently flaring form, which could become extremely elegant. Maillart summarised his criticism of Turner in the following language:

'A form arrived at in this manner will never satisfy the constructive thinking and feeling engineer. He immediately sees that the building material outside the dotted line has no reason for its existence but only disturbs the natural flow of forces because the concave corners always give rise to troublesome stresses. And so the American design is more costly than the rounded form not only on account of the material necessary but also because of the difficulty in shuttering. It is easy therefore to predict that the

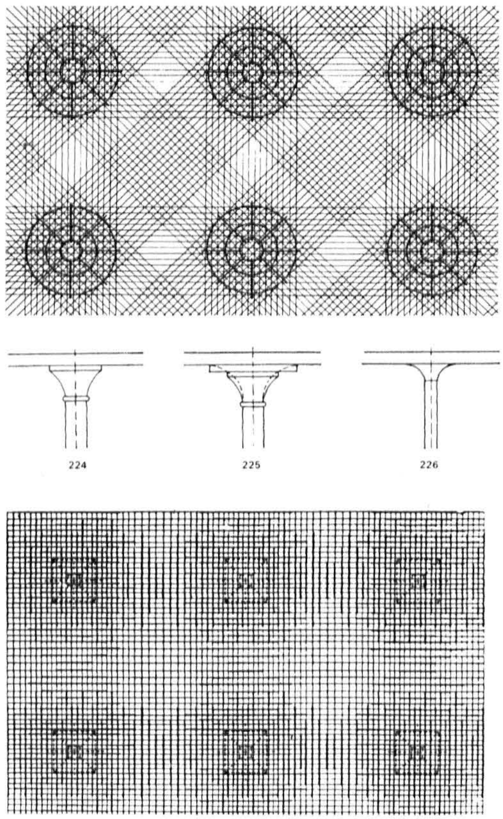

Figure 24. Comparative drawing of Turner and Maillart systems. (from Zur Entwicklung)

American form of column head will yield to the more rational and beautiful European design.'[25]

Whether or not Wright was familiar with Maillart's paper we cannot say for certain, but it is clear that the publication was aimed at the Turner system and its competitors, one of which Wright had used at Richland Center. Maillart had demonstrated that there was no need for the elaborate steelwork of the Barton system. Diagonal reinforcements did not have to pass over point supports, and so there was no need for the drop panel so characteristic of American construction. Maillart omitted everything that was non-functional, and made the slab into a horizontal platform that formed a monolithic body and resisted all stresses and strains within the structure.

As provocative as Maillart's own article was the appendix supplied by the editors of the *Schweizerische Bauzeitung*. It showed Maillart's work at the railroad station in Chiasso, Switzerland, a warehouse at St Petersburg (1912), a box factory at Lancey (1913–14), a spinning mill at Barcelona (1924), and a cable factory at Villanueva (Figures 25–27). In all of these structures the columns were slender, elegant, and refined. The capitals took a variety of forms. Those at Barcelona were eccentrically loaded. That factory was top-lit – rather suggestive for an architect who would later treat the great workroom at Racine in the same way. These illustrations would have come as a revelation to Wright, who had long been troubled by the clumsiness inherent in the American system.

So far we have been discussing only buildings and structural systems. But Wright was an architect whose sense of form permitted him to design all kinds of objects other than buildings: tables, chairs, fabrics, magazine covers, and glassware are only a sample of the problems that he attempted. In my mind the most compelling argument for the impact of Maillart is probably a glass design of 1930. For several years P.M. Cochius, managing director of the Leerdam firm, had wanted Wright to design a dinner service for his firm. In the

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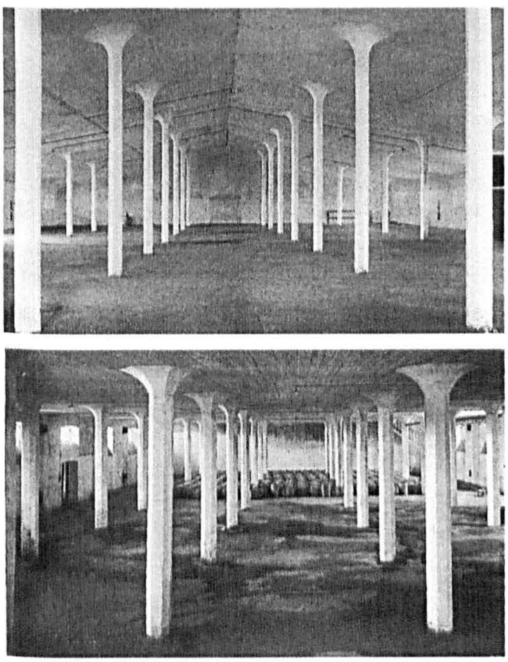
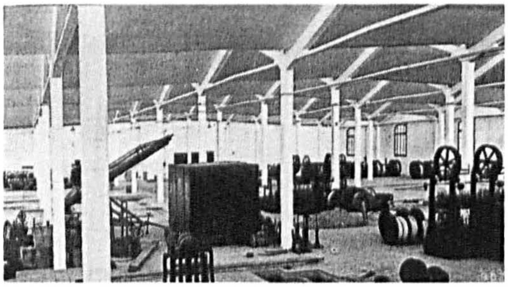


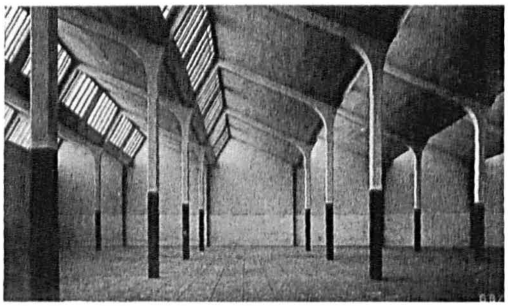
Figure 25. Warehouse at St Petersburg, 1912. (appendix to Maillart article, Zur Entwicklung)

Figure 26. Box factory at Lancey, France, 1913–14. (appendix to Maillart article, Zur Entwicklung)

autumn of 1928 Cochius and Wright met in New York, and the architect agreed to design a set of crystal glassware and a dinner service that could be produced commercially in the Netherlands. Ultimately the glassware drawings comprised 16 pieces in plan and elevation, including glasses for wine, cognac, champagne, and sherry, a finger bowl, and a bread and butter plate. The commission is understandable in the light of two considerations: thanks to the sumptuous publication of his work in the *Wendingen* edition of 1925, Wright was undoubtedly better known in the Netherlands than in any other country of Europe; and the Leerdam Company had a long tradition of employing architects as designers. Among those who had previously been commissioned were Hendrik Berlage and K.P.C. De Bazel. And Berlage, who was still active, had an enormous respect for Wright. So the decision to seek him out was entirely in keeping with company tradition.

Once again Wright demonstrated a cavalier attitude towards the nature of his material, combined with a sense that if a job was not possible at present, it could be accomplished at some point in the future. Johan Ambaum, former curator of the Leerdam Museum, points out that Wright's designs could not be executed because glass-blowing techniques could not be applied.





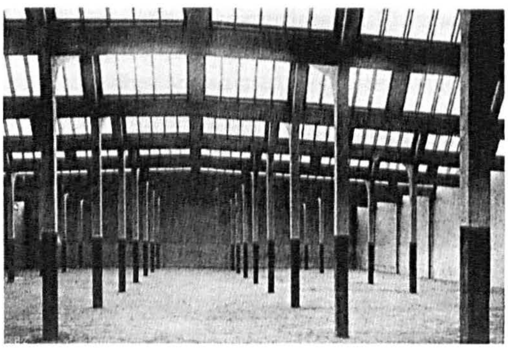


Figure 27. Spinning mill at Barcelona, 1924. (appendix to Maillart article, Zur Entwicklung)

(Cochius advised Wright to go to Corning to study glass fabrication, but there is no record of a visit.) And so, from the original designs only the vase was ever made. Three examples remain: one at Leerdam, one at the Gementemuseum in the Hague, and one at Taliesin. But it is important to note that the technology of glass production has evolved so that it is perfectly possible to produce the candlesticks. Tiffany has the American rights to the design, and they are a popular item. If we compare Wright's drawing for the champagne glass (Fig. 28) with an analysis of the Maillart system (Fig. 29), the similarity is obvious. The drawing is especially significant because it clearly demonstrates Wright's development of two ideas that preoccupied him during his entire career: nature and geometry. Wright thought of his form in the champagne glass as derived from the hemerocallis, a kind of lily, though he must also have been aware of its source in Maillart's buildings. And he gave the glass a hexagonal base, foreshadowing the module in the Hanna house of 1936–37.[26]

The *Capitol Journal* project of 1931 again presented Wright with a project that dictated a slab and column design; this time he was ready to improve on the already elegant Maillart column. This edifice was to be the headquarters for a newspaper in Salem, Oregon. The major structural consideration, as Jonathan Lipman has pointed out, was to isolate the noise and vibrations produced by the printing presses: hence the introduction of the downward-tapering columns set in metal shoes to prevent the vibrations from being conducted upwards. Because of the Depression the project was not carried through, but a drawing in the Taliesin

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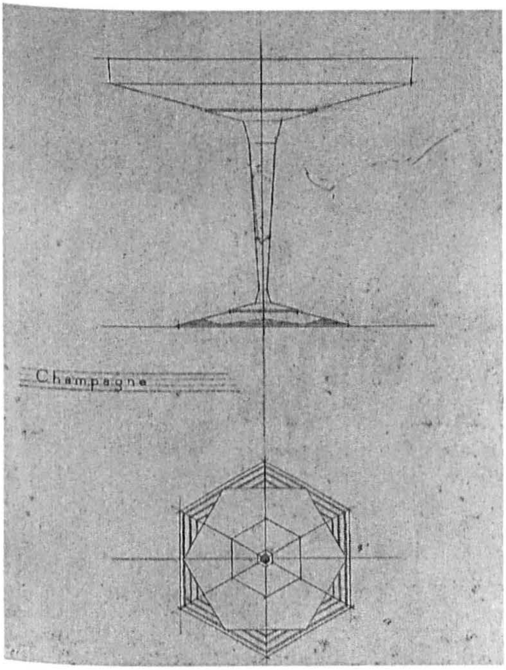

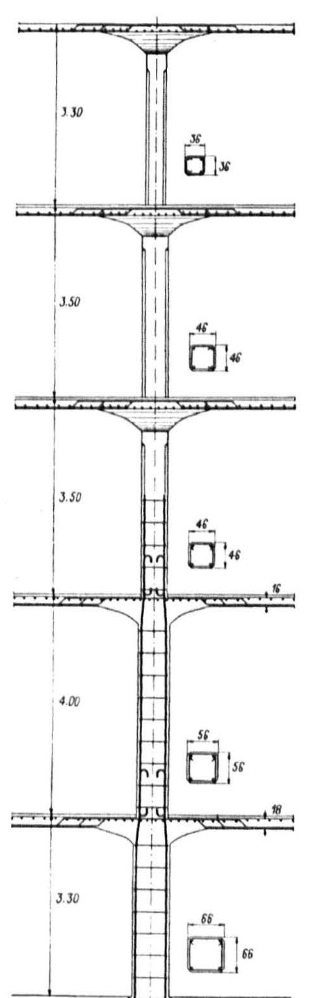

Figure 28. Drawing of champagne glass for Leerdam. (source: Taliesin Archives)

Figure 29. Maillart system (source: Max Bill, Robert Maillart)

Archives shows that the idea of the dendriform (or hemerocallis) column was already fully worked out in principle (Fig. 30). It also, however, carries the designation 'mushroom' – traditional in flat slab construction. And it is important to note that the column connections to each other and the shaft tapering downwards to meet the ground at its weakest point are suggestive of connections that do not carry moments. They are, in fact, as close to 'hinges' as it is possible to go in monolithic concrete construction. Professor Robert Darvas writes:

'If you look at them in that light, they seem to form a series of "3-hinged bents" connected in

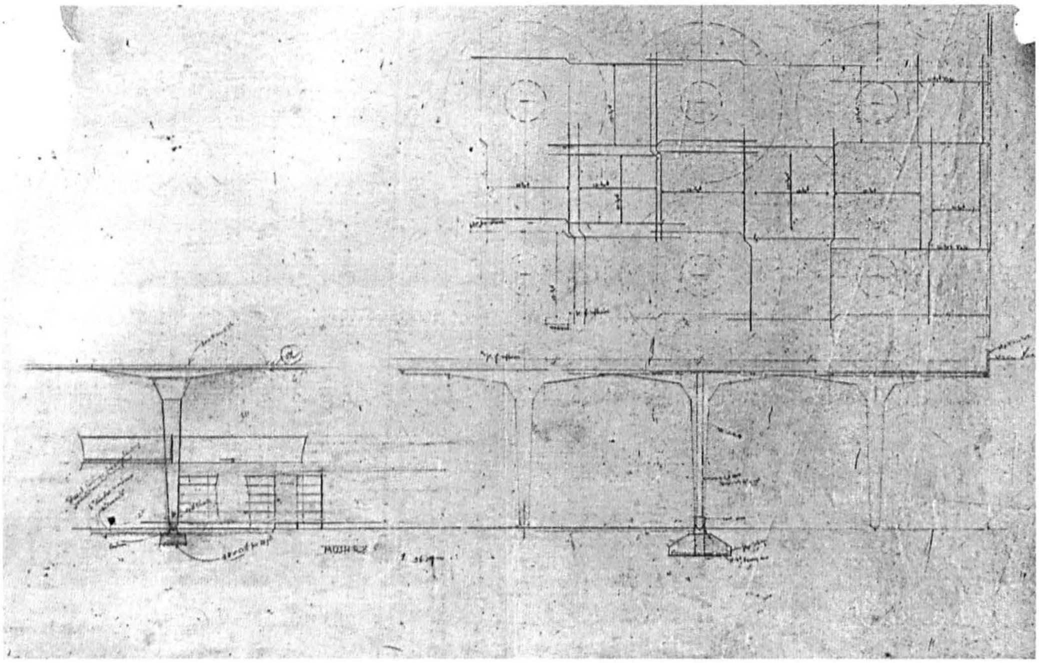

Figure 30. Drawing of column for Salem Capitol Journal project. Frank Lloyd Wright, 1931. (Taliesin Archives)

rows in both directions. Now the 3-hinged bent is very much a statically determinate structure, one of the basic bent forms that can be solved without resorting to statically indeterminate analysis . . . the largest moments will be at the intersection of the mushrooms and their stems i.e. the columns. So the form, while truly artistic and beautiful, naturally follows the statics of the 3-hinged bent and the resulting moments thereof.'[27]

It is important to note that Wright conceived of this form by himself without the aid of any engineer. It is perhaps the best example we have of his own engineering gifts.

The idea of a series of columns conceived as three-hinged bents came to full maturity in the famous great work room at the Johnson Wax Headquarters (Racine, 1939). The requirements of the space of the great workroom lent themselves to a solution very similar to that of the *Capitol Journal* project. Let us begin with the famous presentation drawing (Fig. 31). The proposed structure closely resembles that of the earlier work, but there is a crucial difference: the column is partially hollow. This hollowness can have had only one purpose. It saved weight and thereby enabled Wright to have only a 9 in (225 mm) diameter base. The same reasoning may apply to the hollowness of the calyx and the petals.

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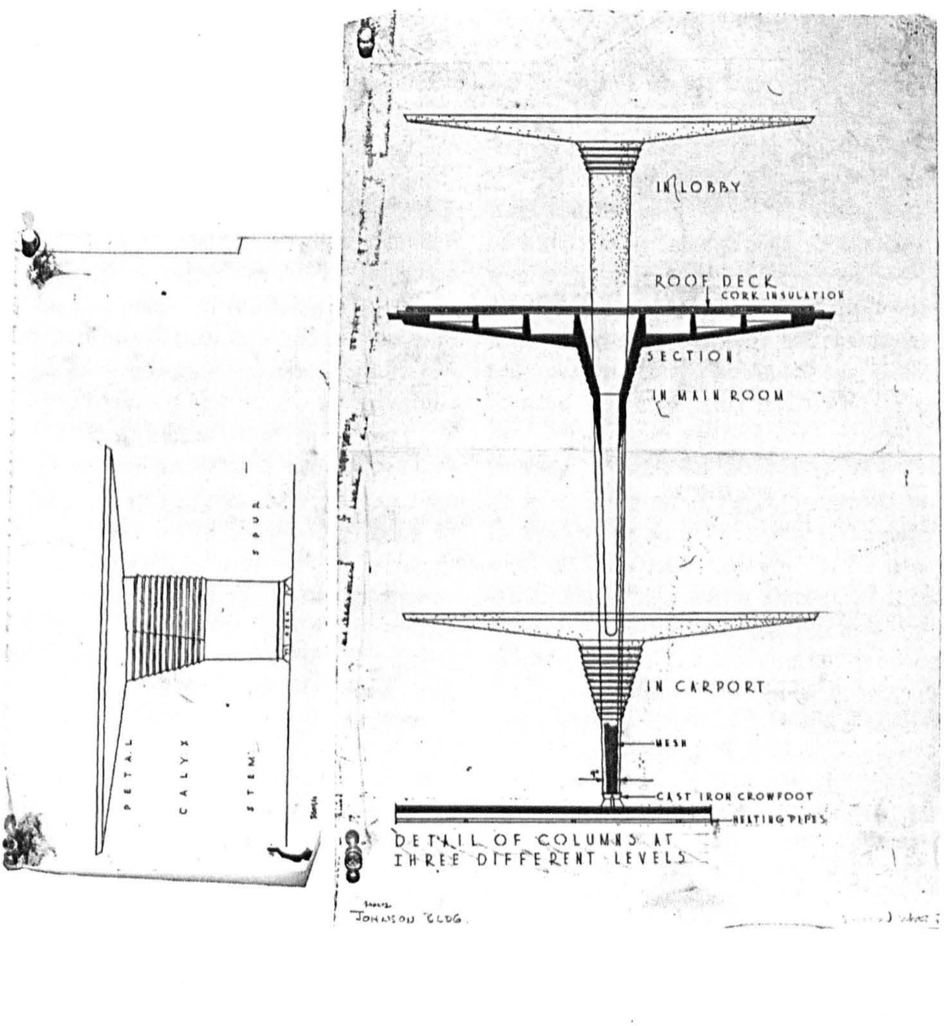

Figure 31. Presentation drawing for column, Johnson Wax Building, Racine. (Taliesin Archives)

The petals are cantilever ribs with dish-shaped circular plates underneath. The ribs are about 2 ft (600 mm) deep at the point of intersection with the calyx, certainly ample to carry the bending. There is no earthly reason to go to this trouble and considerable expense other than weight saving.

The pipe section of the slender column did not much reduce its buckling strength when compared with a solid section of the same diameter. With a 9 in base diameter, the available cross-sectional area governed the overall carrying capacity. Discounting the problem of slenderness, and looking at the column purely from the point of view of strength, the available total strength was 63.6 in^2 area times the 6000 lbf/in^2 specified ultimate strength reduced by a factor of 4 as was common practice in concrete design at that time. The essential calculation is thus $63.6 \times 1500 = 95400$ lb (43300 kg). Since 12000 lb (5440 kg) were assigned to the snow load, that left only about 83000 lb (37650 kg) for the weight of the structure. So Wright and his engineers had to husband the weight of the concrete very carefully.

The foregoing paragraphs differ somewhat from the customary interpretation of the column system at the Johnson Wax building. The columns were not shells or statically indeterminate structures. By definition shells are structures in which the thickness is very small compared with all other dimensions. This is not our case here. Even near the top, under the calyx, where the stems widen to about 2 ft (600 mm) in diameter, a 3.5 in (89 mm) thickness is considerable. We suggest that instead of being a shell, the stem may be thought of as a tapered pipe column. Carl Condit is correct in pointing out that the columns and their interconnecting beams do form a continuous multi-support rigid frame. So far so good. But he continues: '. . . the resulting absence of bending in the column makes possible the use of an extremely narrow, virtually hinged bearing at the column foot.'[28] With all due respect, Professor Condit misunderstood the system. The whole design concept is to provide hinges at the base. In the mid-1930s engineers were generally afraid to have base connections that were 'undefined'. Wright, Peters, and Glickman, however, understood that narrowing the column to a point ensured that the structure would work according to the model assumed in their calculations. Having a hinge at the base, of course, does not make a column free of bending elsewhere in its length. But if the column's tributary area is loaded in a centrally symmetrical way, there will be no bending in the column at all. Because of the continuity and the unavoidable differences in loading conditions and their distribution, there will be bending moments in the columns, but these diminish to virtually zero at the base.

In short, the simple modelling, most probably used by Peters, is that of a series of three-hinged arches. This modelling was certainly suggested, but not worked out in detail, in the 1931 project for the Salem *Capitol Journal*. At Racine the small stiffness of the column bases and the deliberately small sections of the ribs connecting the petals qualify the system for the simplifying assumption of 'perfect' hinges. These would make the overall system stable and statically determinate, enabling the designer to get a reasonable handle on the flow of forces and provide sufficient strength at each point to satisfy the forces present at those sections. The assumption of a statically indeterminate frame thus became unnecessary. The components within the structure – that is, a pipe column and a circular plate – were well described in the engineering literature at least a decade before the design of the Racine building. And, as we have previously remarked, Wright had plenty of time to read that literature, and in Peters he had an engineer who was also familiar with it. So it is not really surprising that Peters recalled that Wright drew the columns and specified their dimensions: there was some adjustment in the thickness of the petals, but the stems were built ' . . . precisely as Wright had intuitively drawn them.'[29]

Here is the place to enter a gentle demurral to the general characterisation of the columns as 'dendriform'. Numerous scholars and historians, beginning with Wright, have likened the Racine columns to trees. The difficulty is that trees do not stand on point supports. They generally get wider and stronger near the ground, and act as cantilever structures. Hence the columns are not trees. The overall effect for the casual observer may resemble a forest canopy, but this canopy rests on supports that are not very tree-like (Fig. 32).

Of course there remains one extremely provocative query about the columns: where did Wright get the idea of tapering his columns to a narrow base? This is an unusual practice in twentieth-century architecture. One finds it occasionally, as in Auguste Perret's columns at Le Havre from a later date. A deconstructionist might argue that in the course of his examination of the literature on concrete he ran across something like this photograph of 1918 (Fig. 33). It shows the space around a column during a test, and it is a provocative instance of photographic distortion. If this were indeed the case, we would have an interesting example of an architect seizing upon photographic error and using it to push back the limits of the structural art. It would be an episode akin to the deliberate misreading of text that is so central to the theory of the literary deconstructivists. It is a possibility.

But we do not think that it was capriciousness or the misreading of a photograph that caused Wright to adopt an inverse taper for his columns at Racine. Throughout his career he was an architect who thought almost entirely in terms of form. He began with an interest in slabs as enclosing and roofing elements. In a certain sense the column with its mushroom-shaped capital, as in the system of C.A.P. Turner and his American contemporaries, was a necessary evil. At the Richland Center warehouse he altered the shapes of his capitals to make them closer to the kind of forms that he desired, but he did not alter the shaft of the columns. In the Salem *Capitol Journal* project he proposed for the first time the narrow base that was his greatest innovation. It displayed both structural good sense and aesthetic sensibility. The idea came to fruition at Racine. Concerning the columns there Professor Grant Hildebrand notes that

' . . . they could have been appropriately tapered in the more conventional way if Wright had envisioned them as being at one with the floor, rising, as it were like tree trunks from the forest floor. In

Figure 32. Great workroom, Johnson Wax Building. (photograph by Jonathan Lipman)

that case, both visually and structurally the pad would have been perched on the top of the mast. Clearly, though, Wright envisioned the shaft and the pad as a unit, acting as a single piece coming to rest on the floor rather than rising from it – the cast iron crowsfoot makes that clear – and in that case both structurally and visually one wants rigidity where shaft and pad meet: hence the inverse taper is appropriate on all counts. (And incidentally, these are the only two possibilities. A cigar-shaped column, with delicate connections at both top and bottom, would offer no lateral stability and thus would collapse like placing cards perched on tooth-picks. You can easily grasp the two viable possibilities by imagining a number of funnels set bell downward, on strong sticks embedded in clay, with cardboard on top, perfectly stable – or, as Wright did it, a number of funnels set bell upward with

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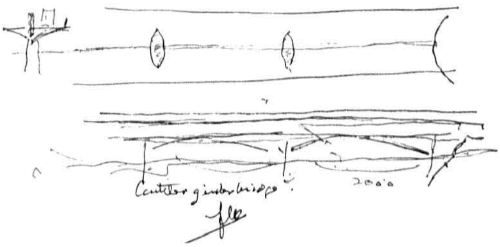

Figure 33. Photograph of 1918 column in Built by the Leonard Construction Co.

Figure 34. Xerox from May 1948 drawing on menu. (Frank Lloyd Wright)

lips taped or glued together, also perfectly stable and considerably more innovative.) And also – and this may well be an important point – the second option yields a skylighting as a natural – and organic? – consequence of the structural concept – and surely this sense of a natural and inevitable relationship of structure and light is very much what strikes one as the beauty and wholeness of the idea.'[30]

Thus the inverse taper for the columns at Racine was a combination of structural good sense and aesthetic sensibility.

Wright's interest in dendriform construction did not end with the Johnson Wax Administration Building. In late May 1948 he visited Louisville to lecture at the Playhouse on the University of Louisville campus, and the following morning had breakfast with Mayor Charles Farnsley and Professor Walter Creese, then teaching at the University. Apparently the trio got along famously. Wright started to sketch unbuilt projects on the backs of menus. Among his drawings was a bridge that he hoped to build over a river in Wisconsin (Fig. 34). The state highway department would not let him carry it through, but he was very fond of the idea. Again the lily pad columns are unmistakable.[31]

Wright often said that the sources of his architectural design were in the natural world. And there is no reason to doubt his statements. But it is equally true that his sensibilities collided with an ancient predilection in Western architecture for the column as an expressive element. In his early years he worked primarily with slabs, and at Unity Temple used them masterfully. A few years later he became aware of the improved slab and column system of C.A.P. Turner. Indeed, he himself proposed slab construction in his 1912 project for the *San Francisco Call*, and he used the Barton system in his A.D. German warehouse of 1915. During the 1920s his practice turned on other issues, but he became aware of the achievements of Maillart and Moser, both of whom worked primarily in concrete. The Racine buildings for Johnson Wax stand as a triumphant vindication of his thinking about the role of the concrete column in architecture.

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2. Frank Lloyd Wright, *In the Cause of Architecture: Essays by Frank Lloyd Wright for Architectural Record (1908–1952)* (New York, 1975), p. 205.
3. *Ibid.* p. 208
4. Wright's attitude towards structure is brilliantly discussed in Grant Hildebrand, *The Wright Space: Pattern and Meaning in Frank Lloyd Wright's Houses* (Seattle, University of Washington Press, 1991), pp. 176–7. In a communication to me of 1 July 1996 Professor Emory Kemp remarks on the deflection now visible at Fallingwater (1937).
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6. H.R. Hitchcock dated the Yahara Boat Club project at 1902: *In the Nature of Materials* (New York, 1942), p. 49. In a remarkable piece of scholarly detective work Dr Jack Holzhuetter of the Wisconsin Historical Society has demonstrated that the Yahara Boat Club project must be dated at 1905, almost simultaneously with Unity Temple: 'Cudworth Beye, Frank Lloyd Wright and the Yahara River Boathouse', *Wisconsin Magazine of History* (Spring 1989), 163–96.
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15. H. Allen Brooks, *The Prairie School: Mid-West Contemporaries of Frank Lloyd Wright* (New York, 1976), p. 195.
16. Margaret Scott, *Frank Lloyd Wright's Warehouse in Richland Center* (Richland Center, 1986), p. 106.
17. Walter C. Edge, *Flat Slab Construction*, p. 462. Edge's article in *The Concrete Engineers Handbook* (New York, 1918) is an excellent summary of what was known about flat slab construction in the United States by 1918.
18. Francis M. Barton was granted US Patent #1,155,461 on 15 October 1915. His application was filed 24 June 1907. I am unable to determine the reason for the long delay. Of course a good deal of work could have been done with the system while the patent was pending.
19. Scott, *Frank Lloyd Wright's Warehouse in Richland Center*, pp. 121–2.

20. From these remarks I must exempt certain early works such as the porch on the Blossom House (Chicago, 1892) and the arcade in the Winslow House (River Forest, 1893). The problem of the column may even account for Wright's difficulties with furniture. A chair leg is, after all, necessarily a kind of column.
21. Peter Collins, *Concrete: The Vision of a New Architecture* (New York, 1959), p. 200.
22. *Ibid.* p. 201.
23. Frank Lloyd Wright to Werner Moser, 25 July 1929, in Frank Lloyd Wright, *Letters to Architects*, ed. Bruce Brooks Pfeiffer (Fresno, CA, 1985), p. 76.
24. David S. Billington, *Robert Maillart's Bridges: The Art of Engineering* (Princeton, 1979), p. 57. Billington notes that Maillart derived the correct amount and location of reinforcement by measuring the vertical bending of the overall slab. Lord measured the strain on individual reinforcing bars and obtained faulty results because he failed to include the tension taken by the concrete. Maillart observed the behaviour of the whole system: 'Den konstruktiv denkenden und fühlenden ingenieur kann aber die so gewonnene Form nicht befriedigen; er sieht ohne weiteres ein, dass das ausserhalb der punktieren Linie liegende Baumaterial keinen Daseinszweck hat und das kalare Kräftespiel nur stören kann, denn einspringende Kanten geben immer Anlass zu unwillkommenen Spannungen. Dabei stellt sich die amerikanische Anordnung night nur infolge des grössern Materialaufwandes, sondern auch der schwierigen Schalung wegen teurer als der gerundete Übergang.'
25. Robert Maillart, 'Zur Entwicklung der unterzunglosen Decke in der Schweiz und in Amerika', *Schweizerische Bauzeitung* (22 May 1926), 263–5. This article is available in a good English translation in Max Bill, *Robert Maillart: Bridges and Constructions* , 3rd edn (New York, 1969), pp. 165–6. Bill, however, added certain diagrams that do not appear in the original article, and omitted the somewhat chauvinistic last paragraph: 'Es ist deshalb vorauszusehen, dass das amerikanische Vierbahnensystem und die ebenfalls aus Amerika stammende Pfellerkopf-Ausbildung der rationelleren und schöeneren "europäischen" Ausführungsart weichen wird.' And he did not show all the illustrations that were added by the editors in their illuminating appendix to the original article.
26. For the Leerdam episode see David Hanks, *The Decorative Designs of Frank Lloyd Wright* (New York, E. P. Dutton 1979), pp. 185–6. A more comprehensive account is Johan Ambaum, 'Ontwerpen van Frank Lloyd Wright voor de glasfabrick Leerdam', *Jong Holland, tifdschrift voor beeldende kunst en vormgeving in Nederland na 1850* (Introductionummer November 1984), 35–51.
27. For the best description of the *Capitol Journal* project see Jonathan Lipman, *Frank Lloyd Wright and the Johnson Wax Buildings* (New York, 1986), pp. 9–11. Professor Robert Darvas very kindly communicated his analysis to me in a letter of 4 February 1993. Recently Professor Donald Leslie Johnson has published 'Frank

Lloyd Wright's design for the *Capitol Journal*, Salem, Oregon, 1932' in *JSAH*, LV (March 1996). My criticisms of that article are published in a letter to the editor of the same periodical in the October 1996 issue.

28. Carl Condit, *American Building Art: the Twentieth Century* (New York, Oxford University Press, 1961), p. 174.
29. Lipman, *Frank Lloyd Wright*, p. 56.
30. Grant Hildebrand to Leonard Eaton, 6 February 1990. As so often in his practice, Wright took a good idea, improved on it, and did not acknowledge his source. However, in the list of engineers whom Wright included as 'collaborators' in his presentation of the mile-high skyscraper in 1956 he mentioned Pier Luigi Nervi of Italy, Eduardo Torroja of Spain – and Maillart of Switzerland. Wright's enthusiasm for Swiss bridges is known. We suggest that it extended to Maillart's elegant flat slab systems.
31. Personal communication, Walter Creese to Leonard Eaton, 18 April 1992.