The Chicago Frame

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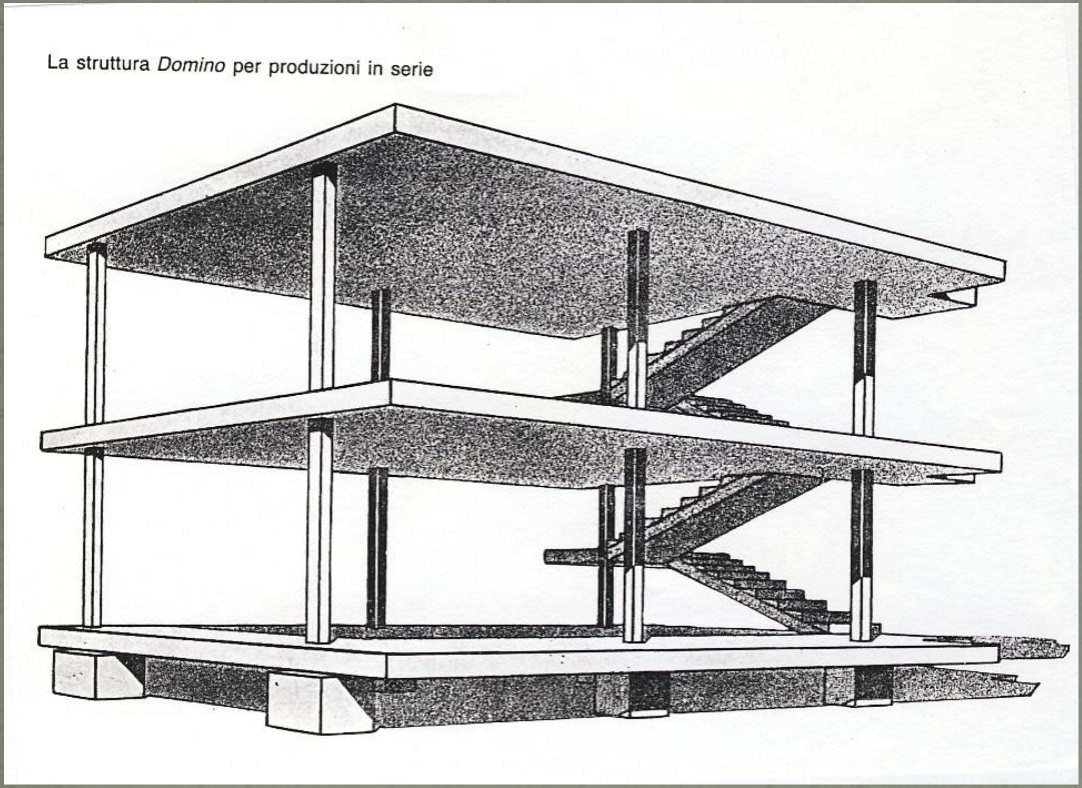

Le Corbusier, Maison Dom-ino, 1914

"The **skeleton of the steel or concrete frame** is almost certainly the most recurrent motif in contemporary architecture, and is surely among the most ubiquitous of what Siegfried Giedion would have designated its constituent elements. Perhaps the **role of the frame** is most aptly summarized in the drawing by which **Le Corbusier** illustrated the structural system of his experimental Dom-ino House, but, its primary function is evident, apart from his practical value, the **frame has obviously acquired a significance** which is less recognized" (Colin Rowe)

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- "The **frame** has been the catalyst of an architecture; but one might notice that **the frame has also become architecture, that contemporary architecture is almost inconceivable in its absence**. Thus, one recalls innumerable buildings where the frame puts in an appearance even when not structurally necessary; one has seen buildings where the frame appears to be present when it is not; and, since, the frame seems to have acquired a value beyond itself, one is often prepared to accept these aberrations. For, without stretching the analogy too far, it may be fair to say that **the frame has come to possess a value for contemporary architecture equivalent to that of the column for classical antiquity and the Renaissance.**" (C.Rowe)

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Le Baron Jenney, The Reliance Building, II, 1891, Chicago

"It is the universality of the frame and the ease with which it has apparently directed our plastic judgment which has lead to the focusing of so much attention upon the Chicago commercial architecture of the eighties and early nineties. In Chicago, seemingly, our own interest were so directly anticipated that if the frame structure is the essence of modern architecture, then we can only assume a relationship between ourselves and Chicago comparable to that of the High Renaissance architects with Florence, or the High Gothic architects to the Ile-de-France, although the steel frame did make occasional undisguised appearances elsewhere, it was in Chicago that its formal result were more rapidly elucidated." (C.Rowe)

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Considered the first American skyscraper, the 10 story **Home Insurance Building in Chicago** (1884-5) was the first tall building to be supported by a **metal skeleton of vertical columns and horizontal beams**. Engineer William LeBaron Jenney discovered that thin pieces of steel could support a tall building as well as thick stone walls could. The steel necessary to carry Jenney's 10-story building weighed only one-third as much as a 10-story building made of heavy masonry.

Since the steel skeleton supported the weight of the entire building and the exterior wall was really just a skin to keep out the weather, the Home Insurance Building was the **first tall building to have many windows**. Jenney's steel frame brought floor space and windows to the structure we now know as the modern skyscraper.

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The City of Chicago is called by some the "birthplace" of the modern tall building. Initially iron, and later, steel framing was the trademark of architects like William Le Baron Jenney, Burham and Root, and Louis Sullivan who were part of the post Chicago 1871 fire building boom.

The use initially of iron, then of steel framing allowed for the birth of **curtain wall buildings.** Although the Bessemer converter was invented in 1867, around the time of the Chicago building boom (1891), a mix of both iron and steel framing could be found.

Up to the invention of the steel frame, high rise buildings were reliant on load bearing masonry walls.

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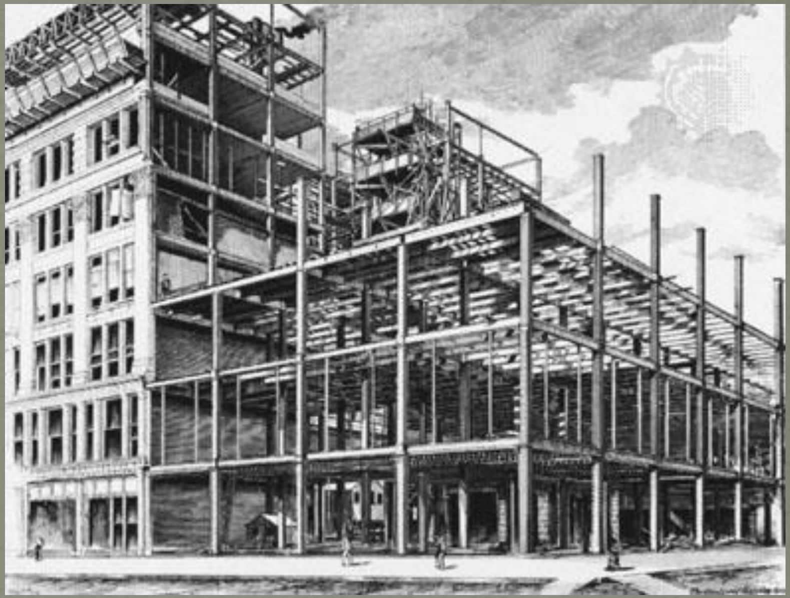

The **Fair Store** (LeBaron Jenney, 1892) stood eleven floors and was considered the largest retail establishment of the city. Also employed were **concrete fireproof tile arches** set between the **floor joists**. Unfortunately the facades of the Fair Store were timid architecturally and were a missed opportunity for a design perspective.

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L. Sullivan, Guaranty Building, Buffalo, 1896.

The **Guaranty Building, which opened in 1896**, is recognized as an outstanding example of **Louis Sullivan's** innovations.
In the 1890s, the steel skeleton skyscraper was a new and uniquely American building type. Most early skyscrapers borrowed heavily from more traditional European design and used strong horizontal lines to de-emphasize their verticality. Sullivan wanted a bold architectural style for the new building type that would express the confidence and prosperity of the United States at the end of the 19th century. He rejected traditional designs and celebrated the **skyscraper's verticality.**
The Guaranty Building makes ornament the focus through the use of terra cotta to cover two full exterior surfaces.

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L.Sullivan, Wainwright Building, St. Louis Missouri, 1891.

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As late as 1890, **iron enjoyed significant advantages over steel** in both reputation and cost. It had been used extensively in two **forms—wrought and cast**—since the mid-eighteenth century, when, as a product of the industrial revolution, it proved its merits in machinery and bridges and then found widespread use as a (more or less) fireproof material in mill construction of the 1790s and early 1800s.

"Wrought" and "cast" referred to the methods of iron production, but also to chemical content.

Cast iron was closer to **raw pig iron** in its **high carbon** content. It was a strong but brittle material that could not be easily worked except at temperatures near melting.

Wrought iron, on the other hand, relied on time and labor-intensive puddling to **remove carbon**. This resulted in a loss of strength, but also— critically—an increase in ductility at relatively cool temperatures that meant it could be hammered or rolled into useful shapes. Together, these two forms of iron predominated in most early tall building construction, from the 1851 Crystal Palace to early skyscrapers in New York and Chicago.

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Despite the apparent lack of incentives for the conversion, the extraordinary replacement of cast and wrought iron by steel took less than a decade, from the first publicized use of steel in building construction in the **Home Insurance Building** (left) in Chicago in 1885 to *Engineering Record*'s definitive pronouncement in 1895 that cast iron "could not be recommended" for structural purposes. What occurred in the intervening decade paired a gradual growth in the scientific understanding and testing of steel—leading to its acceptance as a reliable and calculable product—with the realization that its unique combination of strength and ductility allowed it to satisfy one of the great requirements of skyscraper **construction—wind bracing**—in ways that cast and wrought iron could not.

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- **The problems presented by wind in tall building** construction were threefold. First, as buildings were built ever higher in proportion to their base, the overturning moment created by a gust of wind striking their sides increased dramatically.
- Buildings functioned as **giant, vertical cantilevers**, firmly anchored at the base, with a distributed load of wind over their entire surface.
- **Taller buildings presented exponentially more difficult problems**, as their increased area of exposed wall gathered wind load and increased the length of the lever arm by which wind could pry the building out of its foundations.
- Heavy masonry and hybrid masonry and iron buildings offered natural resistance to this prying action, as their windward exterior walls were far too heavy to be lifted by the wind's leverage.

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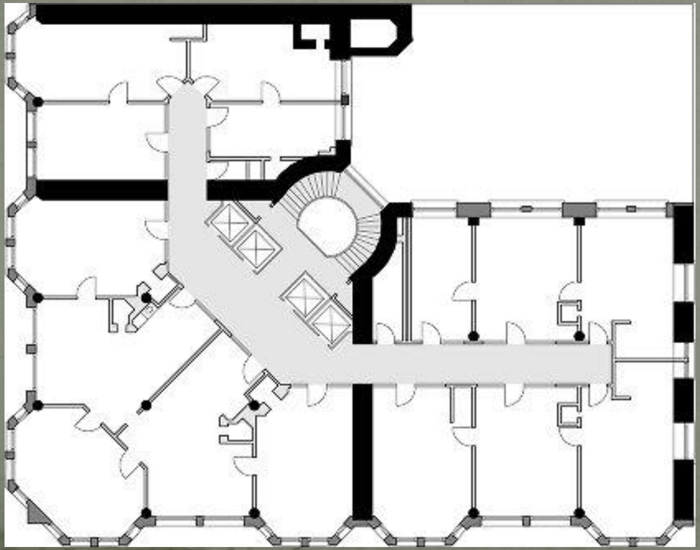
Holabird and Roche, Tacoma Building, 1889 .



However, the lighter skins of the skeleton era no longer offered large-scale wind resistance through simple weight, and after Holabird and Roche's Tacoma Building (1889), architects moved wind-bracing masonry walls inside, leaving the skins free from thick, light-blocking walls, but taking up valuable floor space. While buildings without steel could resist the overturning effects of wind, the internal stresses induced by such resistance could be formidable, as these structures had to accept both wind-induced shear and bending throughout their frames.

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Burnham and Root, the Rookery, Chicago, 1888.

Before the late nineteenth century, **wind bracing** had rarely been more than a minor consideration in structural calculations, because in heavy masonry buildings the dead weight of brick or stone construction absorbed all but the most severe lateral and overturning forces imposed by wind.

However, the **lighter weight of skeletal buildings, their increased height, and the nature of steel and iron connections** necessarily brought this issue to the fore.

The designers of the tall buildings of the 1880s in Chicago were among the first to recognize this problem and to solve it with dedicated lateral or shear systems.

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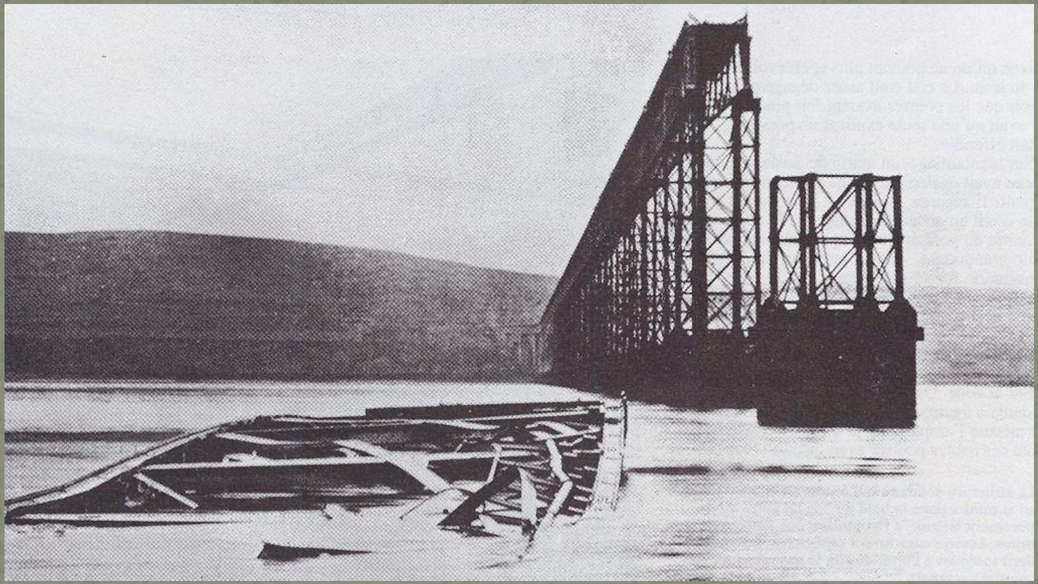

Concerns about the **performance of connections** had real implications. In December 1879, the Firth of Tay Bridge in Scotland collapsed in winds that were well within its claimed structural limits. A subsequent investigation proved that the bridge failed through a combination of **poorly designed and manufactured connections**. The geometry of the bridge's supports created huge tensile loads on its diagonal bracing members. These members were connected by bolts whose holes were found to be imperfectly cast and aligned.

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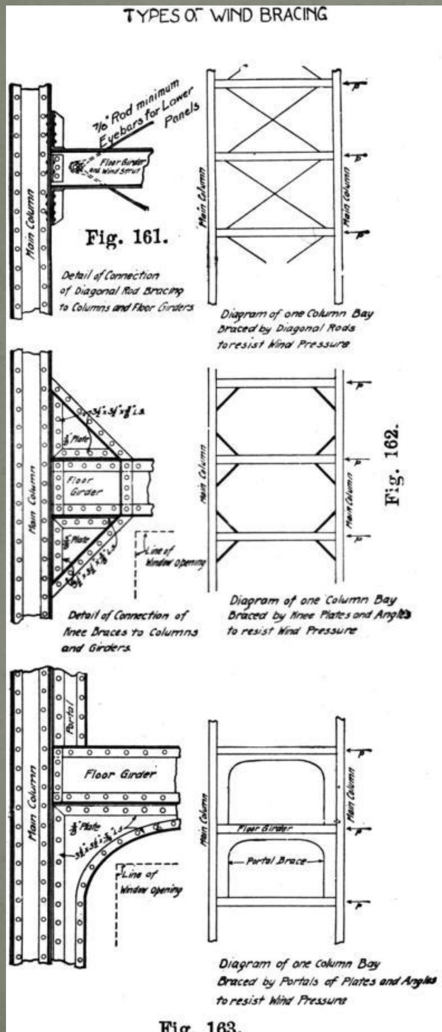

Wind bracing became an important part of structural frames as a matter of course in the boom of 1890–91, and it took three different forms. Each system relied on metal rather than masonry, eliminating weight. Each allowed plans and façades that were more open than the masonry systems of the previous decade. Each also depended upon increasingly precise standards in manufacture, since the Tay Bridge disaster had pointed out that slackness in structural connections due to imperfect geometries or alignments could lead to failure through repeated dynamic loading. These three frame-based wind- bracing schemes added members or connections to make building frames act as cantilevered, vertical trusses.

From the top: cross bracing, knee and portal bracing.

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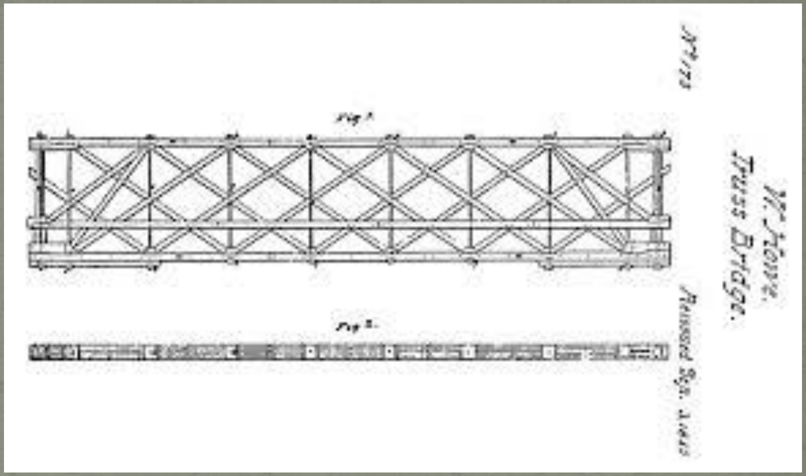

As masonry walls were reaching their practical limits, **the metal frame**, which was an efficient system for resisting gravity loads, was also being recognized as an efficient system for withstanding wind forces. Here the world of bridge engineering, where large iron and steel cantilevers were common, showed the way forward. Railroad bridges employed **trusses** to absorb gravity loads, using triangular geometry to achieve cantilevers and single spans with far less weight than traditional masonry arch bridges. By taking bridge trusses and standing them on end, engineers had a valid model for designing against wind loads. Engineered trusses could be used in place of masonry walls to absorb the bending and shear of lateral loads, eliminating substantial weight.

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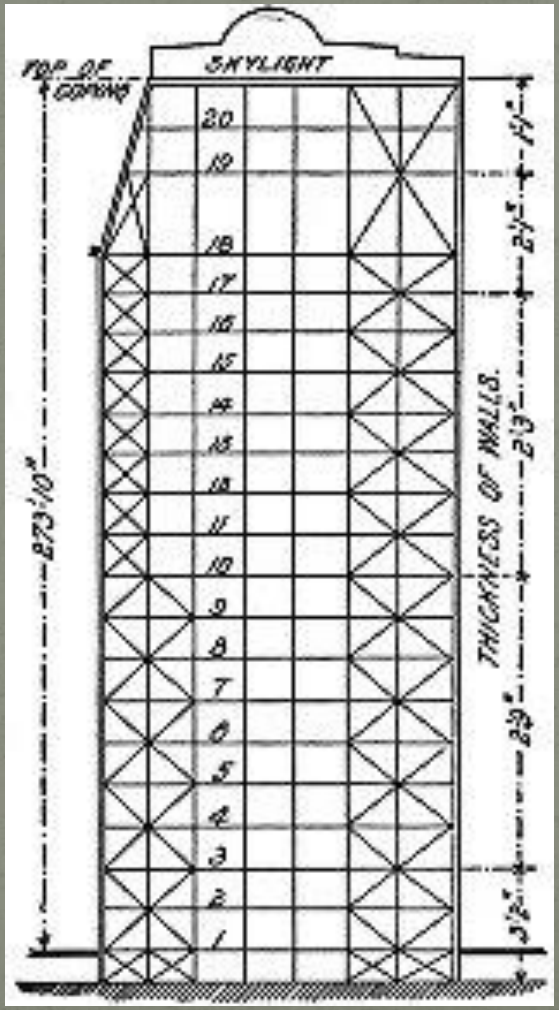
Burnham and Root, *Masonic Temple, Chicago 1892.*



Of these structural systems, the most similar to **actual bridge construction was rod- or sway-bracing**. This technique employed diagonal tension members set within rectangular panels of the building frame, and connected, typically, to intersections of column and girder. The resulting cross bracing triangulated each panel, providing a shape that could **resist loading through its geometry**.

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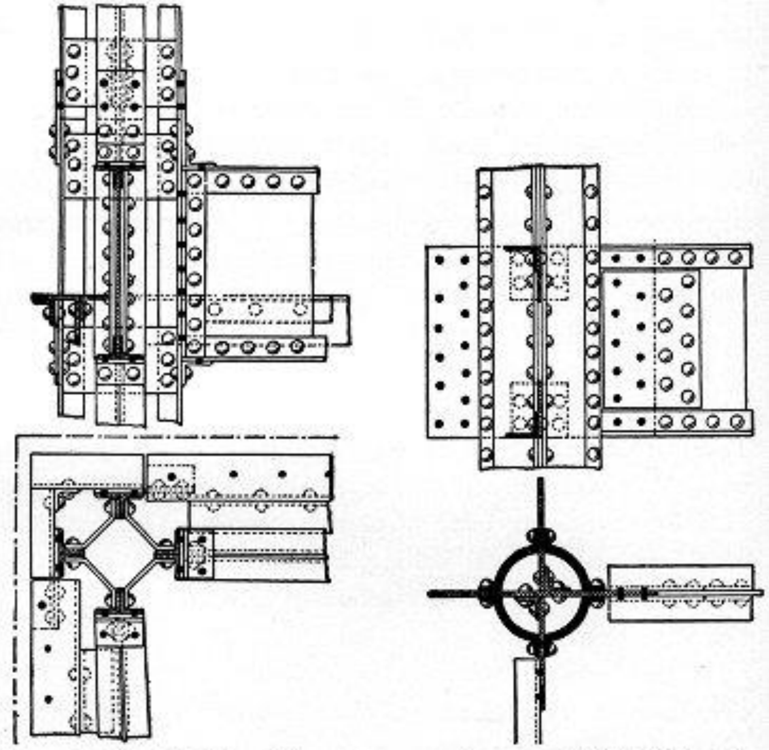

Fig. 118.—Detail of Gray Column and Connecting Girders.

Fig. 119.—Detail of Phœnix Column.

Riveting entails heating metal plugs to the point of soft pliability, inserting them into pre-drilled holes in two metal plates, and then hammering both ends of the plug flat (or with a slight dome). **This fills the hole completely with hot metal** and, once cool, the two pieces are held together with a durable mechanical connection.

Riveting had emerged as a technique for connecting wrought iron before 1850, and its strengths and potential flaws were rigorously examined by William Fairbairn in 1872.

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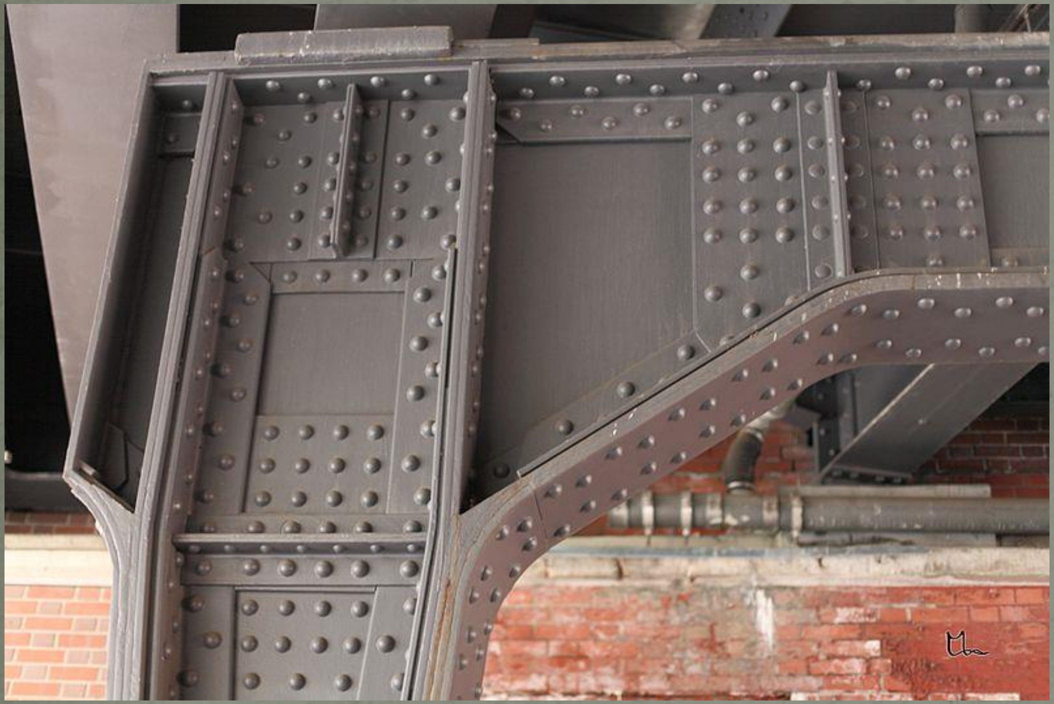

The major advantage of **riveting over bolting** lay in the compression of the soft, hot rivet metal within the joint, which would completely fill even an imperfect hole, guaranteeing full bearing of the rivet on both elements; as the rivet cooled, it also shrank, tightening elements to one another.

A riveted connection offers remarkable stiffness and reliability.

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Writing in 1896, William Le Baron Jenney argued that the **switch from cast-iron to steel columns had been the most crucial development in the realization of the tall metal frame:** "Since the Home Insurance Building, the most important improvement that has been made in this class of construction, now generally known as the Chicago construction or **the steel- skeleton construction**, was the introduction of steel-riveted columns, which are now made cheaply and in all respects thoroughly satisfactory. All the assembling at the building is done with hot steel rivets; increased rigidity is secured, as well as a material reduction of the weight of the columns. Steel-riveted columns as now manufactured are considered perfectly safe with a coefficient of safety of 4, while for cast-iron columns a coefficient of safety of 8 is not considered other than reasonably safe".

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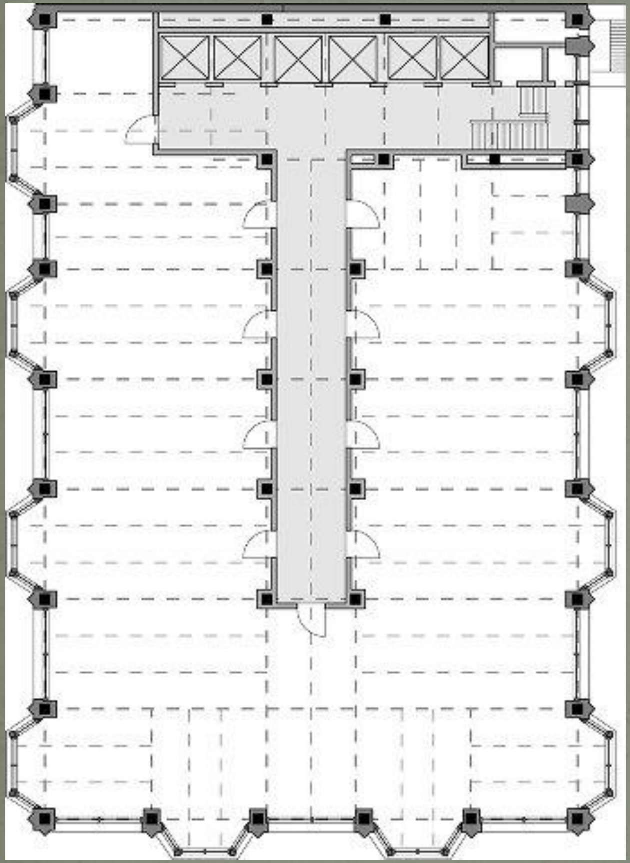
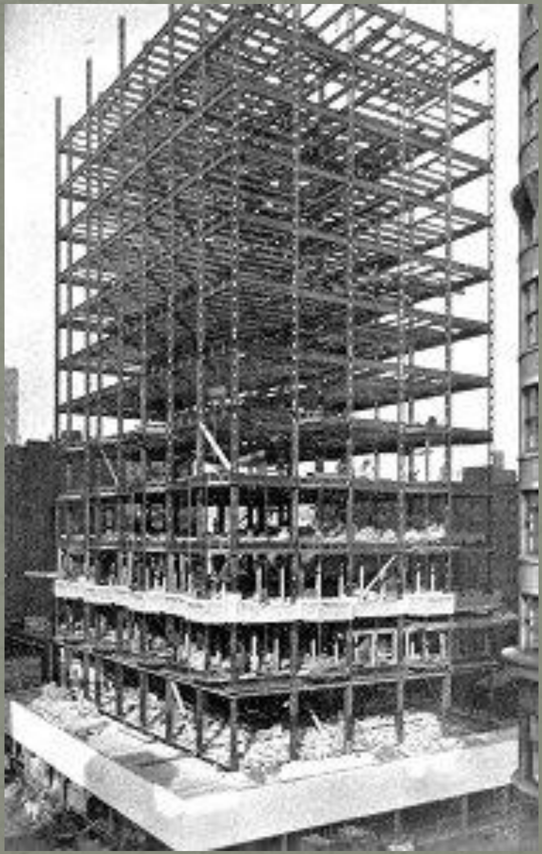


Burnham and Co, Fisher Building , Chicago, 1896



The first syntheses of riveted steel construction, stiff moment connections, and columns shaped to perform in concert with girders in standing against wind forces were the Reliance and Fisher Buildings in Chicago (1895 and 1896). Both were designed by D. H. Burnham and Co., with Charles Atwood as lead designer and Edward Shankland the engineer.

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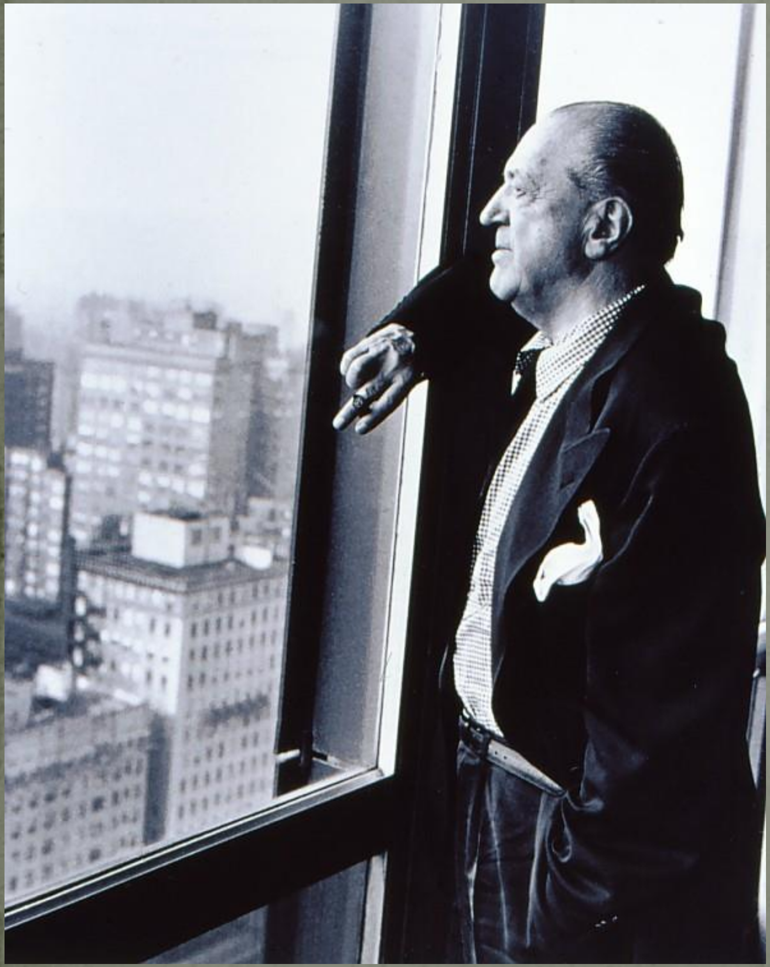

Ludwig Mies van der Rohe (1886-1969) was a German-born architect known as the leader of the International Style.

Ludwig Mies van der Rohe's first great work was the German Pavilion for the 1929 International Exposition in Barcelona. Mies moved to the U.S. in 1938, and the International Style, with Mies its leader, reached its zenith during the next 20 years. Modernist steel-and-glass office buildings influenced by his work were built all over the world over the course of the 20th century.

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Mies van der Rohe, Friedrichstrasse Skyscraper project, 1921

This design for a **crystal tower** was unprecedented in 1921. It was based on the untried idea that a supporting steel skeleton would be able to free the exterior walls from their load-bearing function, allowing a building to have a surface that is more translucent than solid.

Mies van der Rohe determined the faceted, prismatic shapes of its three connecting towers by experimenting with light reflections on a glass model.

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A number of American skyscrapers had featured expanses of glass, but Mies was the first to imagine such a building without a structural or decorative frame of masonry.

Mies developed his radical proposal in response to a call for German architects to design Berlin's first skyscraper, intended for a triangular site bounded by the Spree River, the busy shopping street Friedrichstrasse, and the train station of the same name.
The competition drew 140 entries as well as intense interest from architects, artists, and the general public, generating debate about the future of the city and representing hopes for new beginnings after Germany's defeat in World War I.

While Mies's bold image of an entirely steel-and-glass skyscraper had a solid scientific and technological basis, his crystal-shaped plan reflected the more fantastic visions of Expressionist architects and artists, who were drawn to glass as a symbol of purity and renewal.

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Mies van der Rohe, Glass Skyscraper project, 1922

The Glass Skyscraper carried Mies's project for the Friedrichstrasse tall building into new aesthetic and structural territory. Photographs of the model show a slender tower whose glass curtain walls describe soft meandering curves .

The plan shows open offices, a central hall, two circular staircases and nine elevators, as well as restroom facilities and a doorman's office.

"I placed the glass walls at slight angles to each other to avoid the monotony of overlarge glass surfaces. I discovered by working with actual glass models that the important thing is the play of reflections, not the effect of light and shadow as in ordinary buildings..."