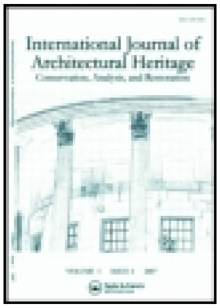

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The Beauty of a Beam. The Continuity of Joan Torras's Beam of Equal Strength in the Work of his Disciples: Guastavino, Gaudí and Jujol

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The Beauty of a Beam. The Continuity of Joan Torras's Beam of Equal Strength in the Work of his Disciples: Guastavino, Gaudí and Jujol

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Joan Torras: The Beauty of the Beam

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ABSTRACT:

Joan Torras, professor of the strength of materials at the School of Architecture of Barcelona (1871–1910), considered the beam of equal strength not only as a structurally extremely efficient beam but also considered it beautiful because of its ability to reflect the material's strength. Joan Torras's structures have left their special mark on Barcelona and on the work of his most illustrious students: Rafael Guastavino in the United States of America published similar structures, but it was Antoni Gaudí and Josep Maria Jujol that transfigured them mimetically for Barcelona's Park Güell and Tarragona's Metropol Theatre respectively. These examples will show how an expressive gesture can thoroughly transform a "technical form" into an "artistic form", a fact that inevitably recalls the wisdom of classical Greek mimesis.

KEYWORDS:

History of Architecture, Barcelona, tile vaulting, reinforced concrete, Joan Torras, Rafael Guastavino, Antoni Gaudí, Josep Maria Jujol, Robert Maillart, Max Möller

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"SAGREDO: [...] It would be a fine thing if one could discover the proper shape to give a solid in order to make it equally resistant at every point, in which case a load placed at the middle would not produce fracture more easily than if placed at any other point."

(Galilei 1638, 137)

On the second day of the *Discorsi* (1638), Sagredo, representing the critical spirit of Humanism, while observing Salviati's demonstrations, perceives the possibility of a perfect beam shaped by material placed only where needed to withstand weight and spared of it wherever unnecessary. As one can see in the drawing by Galileo (Figure 1), despite the inaccuracies of the model (Petroski 1994, 65–80; Heyman 1998, 11–12), the upper edge of this ideal beam with a load at one end forms a parabola and has the particularity that any part of its cross-section CN is tested to its strength limit. This ideal, which pursues a radically optimum design for the bending of the beam, has been the inspiration behind the research of generations of scientists, architects and engineers since Galileo's days. This obsessive research was not only a search for efficiency but also one for beauty.

The Beam of Equal Strength in the Structural Reasoning of Joan Torras

These structural principles were deeply embedded in the theory as well as the practice of the architect Joan Torras Guardiola (1827–1910), a man of his time, with a solid background in mathematics and a fervent supporter of the use of iron in architecture (Figure 2). Torras's importance in the architecture of Barcelona of the nineteenth century (Graus and Rosell 2011, 35–90) resides in the extensive production of iron constructions of his firm and in his duties as professor, first at the Special Master Builder School of Barcelona (1855–70), and then, when this closed, at the School of Architecture of Barcelona (1871–1910). He was the second year professor of descriptive geometry, stereotomy, mechanics and construction of Rafael Guastavino while he was studying for Master Builder and professor of the strength of materials of Antoni Gaudí and Josep Maria Jujol while they were studying Architecture. His teachings were to have a great influence on their architecture.

The classroom notes of his students reflect insistently his “frugal” temperament; as if wisdom and caution in the management of money constituted a kind of purification: it would allow for more at less cost while refining at the same time constructive solutions; making them more simple, practical and functional, in short, more logical. The period between 1873 and 1876 marks a decisive stage in the life of professor Torras, when he decided to build a house for himself at number 74 Ronda de Sant Pere in Barcelona (Torras 1875), using it as a laboratory for his classes. As the architect Bonaventura Bassegoda Amigó explained, years later: “[...] it was here, in this site in the Ronda de Sant Pau that he began building his house, the testing ground for all his plans, the *home* and programme of all his principles brought to life. He would not conform to do as others did, which is why he became a master of his generation, with an eye for the new and rationale. This was in 1873 and he was already thinking about building floors with a slab made from flat brick supported by ribs. At that time (during the early days of cement) this was a novelty.” (Bassegoda 1911, 229–230). Here, the outstanding new feature was the construction of a “new and rational” ribbed floor. As Figure 3 shows, the ribs of the slab follow the shape of the bending moment diagram: in the case of a beam supported at the ends with a point load applied

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at mid span, the beam of equal strength would be shaped like a parabola, but if a beam supports a uniform load, the beam of equal strength would be shaped like half an ellipse. It was a "potbellied" floor, very much like the beam of equal strength described by Galileo and later studied by Hooke, Mariotte, Parent, Euler, Coulomb, Young or Navier, but also in line with those pioneering experiments, carried out by the so-called "practical" English engineers, for the fish-belly rail by William Jessop (1789) and, especially, William Fairbairn and Eaton Hodgkinson's research (Fairbairn 1854) for a design for a rational cast iron beam (1831–54) for the English mills (Figure 4).

There is a fundamental difference, however, between these "potbellied" beams and those proposed by Torras, his are made of iron and brick and not only of iron. In this way the floors combine brick masonry, so typical in Catalan construction, with iron withstanding tensile stresses, bearing in mind the suggestions of the ever-present *Entretiens* (Viollet-le-Duc 1872, 46–47). In this sense Torras's proposal, to suit the material to be used whether the work required tension (iron flat bar on the lower edge of the beam) or compression (brick rib and brick flooring), was more in line with those contemporary experiments with reinforced concrete for fireproofing buildings by William Boutland Wilkinson (1854) (Brown 1966) or Thaddeus Hyatt (1873) (Collins 1959, 58–60). Torras's proposal is only a stone's throw away from reinforced concrete, where iron reinforcement is embedded in concrete.

In any case, Torras must have been pleased with the results because, in 1876, he registered his system as a "privilege of invention" (Figure 5), what we now call a patent, under the name "A new system of hanging beams and floors" (Torras 1876). The term "hanging" which refers to the

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tensioned iron flat bar could also be seen as conforming a catenary. Likewise, the patent also includes Torras's frugal nature: saving material because of the form and by using brick, a material cheaper than iron, for the compressed areas. As Torras observed: "[...] it is common knowledge that a construction whose parts are not all working equally to their strength limit, is faulty" (Torras 1876, [1]).

There can be no doubt that for Torras his investigations into the beam of equal strength were not aimed solely at the technical problem regarding the efficiency of construction materials, but constituted the deep-rooted *leitmotive* of his research for the form of the perfect structure. In this frame of mind, Torras designs the roof trusses of the central nave of the Palau de la Indústria, with its 30 m span, for Barcelona's Universal Exhibition of 1888 (Figure 6). Here he proposes a constant-force gable truss (Allen and Zalewski 2010, 284–285) typified by a top chord inclined according to the needs of the roof and a bottom chord that takes the shape of a parabola (Figure 7) so that the force is constant throughout the top chords (Figure 8), with the consequent saving of material and expressiveness similar to his "new system of hanging beams and floors".

Once designed and put to use, this roofing structure which he called "ala de mosca" (the wing of a fly) would be persistently repeated in Torras's work, be it in his solo projects or in those in collaboration with other architects, and would become his trademark. This structure is present in the Clot (1889) and Unió (1889) markets in Barcelona, in the market in Sitges (1890), and in the demolished Frontón Colón (Pelota Court Colón) (1896) and in the Farinera del Clot (Clot Flour Mill) (1909), both in Barcelona. It was precisely, during the Second National Congress of Spanish Architects, held in September 1888 as part of the Universal Exhibition, that Torras, unaccustomed to writing, would clearly put forth his ideas regarding the relationship between structures and architecture. When he rhetorically asks “What effects do the materials have on and what role do they play in construction? How far reaching is their influence?”, and answers: “[...] for a work to be scientifically acceptable and artistically beautiful, it is necessary that all the material elements that form it suffer to the same degree with respect to their breaking point.” (Torras 1889, 103–104). That is to say, the same argument used for the beam of equal strength. Though, it should be noted that, for Torras the materials used in construction can “suffer” just like a human being, crying with pain or in peaceful slumber... “If a building lacking in harmony could talk, what would it say? Some would emit a dreadful noise, made by the materials working to excess shouting and crying. While others would be sleeping like logs, because they are not exerting any effort, since they are not doing anything. Whereas, when in a building all its constructive elements are working to the same extent, it intones a song, if we understand for its song its mechanical vibrations, harmoniously comparable to a symphony by Rossini.” (Torras 1889, 104).

Thus, for Torras, the beam of equal strength was not only a problem of economic optimisation of a design but also one of constructive sincerity and expressiveness regarding the internal order of the structure, this for him was the indispensable requirement for serious research on formal beauty, a research based on the theory of architecture and on the philosophical discipline of aesthetics. Inquiring into the origin of his ideas, it seems appropriate to unfold two possible paths.

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To begin with, his words echo the Lodolian severity (Rykwert 1976) found in the treatise *Principi di Archittecttura Civile* by Francesco Milizia that could be found in every European architect's library of the time. Recalling the words Francesco Algarotti had Carlo Lodoli say and that Milizia made famous: "nothing should be put on show (*in rappresentazione*) that is not a working part of the structure (*in funzione*)" (Milizia 1785, 31). Thus, for Lodoli and his followers in XVIII century illustrated Venice, everything visible must have a function. And in the case of the beam of equal strength, which has no spare material, its beauty lies in the perception of the parabola as purely a mathematical solution to a structural function.

Secondly, however, Torras's expression "to suffer" also carries in it something of Schopenhauer's philosophy when the latter says "[...] the conflict between gravity and rigidity is the sole aesthetic material of architecture; its problem is to make this conflict appear with perfect distinctness in a multitude of different ways." (Schopenhauer 1819, § 43). That is to say, there could be a psychological projection of the person on the objects of the world, between what man feels from within, his being, and what he perceives from without, the world (Mallgrave 2005, 198–199). Torras, like Schopenhauer, believed that a structure, a dynamic being, was able to take the scientific form that could reflect the deepest conditions in nature's order, which concerning architecture, is gravity. In the words of Schopenhauer: "[...] each part bears just as much as it conveniently can, and each is supported just where it requires to be and just to the necessary extent, this opposition unfolds itself, this conflict between rigidity and gravity, which constitutes the life, the manifestation of will, in the stone, becomes completely visible, and these lowest grades of the objectivity of will reveal themselves distinctly." (Schopenhauer 1819, § 43).

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There can be no doubt that both the ribbed floor, of 1876, and the "fly wing" roof truss, of 1888, were structurally efficient structures, and that their "potbellies" reflect their function to the observer which is to gracefully support weight, under that delicate gesture of "suffering".

Torras was not the only designer of structures working with the formal concept of the beam of equal strength. For example, a few years later, we have the work of the German engineer Max Möller (1854–1935) who, around 1894, in Braunschweig, built with the reinforced concrete manufactures *Drenckhahn und Sudhop* (Drenckhahn 1904), beautiful ribbed bridges that remind one of the beam of equal strength (Figure 9).

On the other hand, one cannot rule out that at the time of designing his "fly wing" roof truss Torras was not familiar with one of the bridges using lenticular trusses like those designed by the German engineer Friedrich August von Pauli (1802–1883) around the middle of the 19th century (Hilz 2002).

Finally, it is important to note the striking similarity between Torras's "fly wing" roof trusses and those designed years later, made of reinforced concrete by the Swiss engineer Robert Maillart (1872–1940) for the *Magazzini Generali* de Chiasso (1924) (Billington 1997, 116–120; Mark et al. 1974; Zastavni 2008). One must not forget that between 1914 and 1925, Robert Maillart had a studio in Barcelona (Miranda et al. 1986; Graus 2012, 486–497) and could possibly have seen Torras's roof trusses (Figure 10).

The continuity of Joan Torras's structural reasoning in Rafael Guastavino

Be that as it may, what is attributable to Torras, without fear or favour, is the impact he had on his students and professional colleagues. As was pointed out earlier, the impact was twofold, one as professor of fifty promotions of master builders and architects, and, two from his iron constructions firm, he advised his by then professional colleagues on their structures, all of whom granted on him the full confidence of a master.

One of Torras's students to appropriate his master's legacy for himself and intelligently multiply it was Rafael Guastavino Moreno (1842–1908), who renewed the construction of tile vaulting in Barcelona by introducing cement and iron tie rods between 1868 and 1881 in the Batlló factory (Graus et al. 2008, 311–363), and later exported the technique to the United States of America where in 1889 he founded the *Guastavino Fireproof Construction Co*. (Collins 1968; Rosell 2002, 44–59; Ochsendorf 2010). While he was still in Catalonia, in 1878, Guastavino patented a construction system of "Vaulted roofs of inter buttresses and discharge", details of which unfortunately are missing (Guastavino 1878). Maybe it was just a mimetic act two years after Torras patented his "A new system of hanging beams and floors". The name Guastavino gives to his patent seems to indicate that it might have elements of tile vaulting compressed by iron tie rods.

Furthermore, to promote the possibilities the tile vaulting technique of his American company had to offer, he published the book *Essay on the theory and history of Cohesive Construction,*

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applied especially to the timbrel vault (1893) where he explicitly recognizes Torras's mastership: "But whatever knowledge I may possess on this subject is due, not so much to my researches and investigations, as to the wisdom of my distinguished professors at the Academy of Barcelona, D. Juan Torras and D. Elias Rogent, who instructed and interested me in the study of the arts and applied sciences, calling special attention to this system of construction in embryo, for which I treasure their memory with gratitude." (Guastavino 1893, 9).

Thus, among other proposals, this 'system of construction in embryo' was further developed in the section "Floors and roofs. How the materials work in them" which included a floor (Figure 11) that reinterpreted Torras's patent of 1876, without mentioning him in the following terms: "One example of this application is a floor constructed with a continuous barrel arch (A), with some small bent rods (B), with a small partition laid over the rod B, rising to the barrel arch. This arrangement will form a continuous beam in which the barrel arch, and part of the partitions will work by pressure, while the rods will work by tension. The material in this position works with its true force." (Guastavino 1893, 103). And goes on to say that material would be placed only where effort was required from it. A precise and efficient application of the concept of the beam of equal strength that Torras had taught him.

Mimetic transfigurations of the beam of equal strength in Gaudí and Jujol

But who truly re-elaborated the legacy of the concept of Torras's beam of equal strength and transfigured it mimetically was Antoni Gaudí Cornet (1852–1926). More exactly, when working

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on Barcelona's Park Güell, Gaudí gave special and thorough thought to flexure and its expressiveness (Collins 1963). Ever since the first biography by Josep Francesc Ràfols (Ràfols 1928, 18–19) the idea of Gaudí's scanty presence at the School of Architecture has been stressed upon, but as Juan José Lahuerta stated, this anecdote has more to do with the hagiography of the Vasarian *Vite* model than the reflection of Gaudí's day-to-day hard-working scholarly work (Lahuerta 2002, 15–18).

The architrave of the Doric hypostyle hall of the Park Güell market (Paricio 1981; Rovira Pey 1990; Martínez Lapeña and Torres 2002) at a glance appears to be a canonical architrave with a straight and smooth lower face, as all architectural treaties dictate. But on closer observation a slightly "potbellied" architrave is perceptible. In the photos of the park in construction the lower curve is clearly observable (Figure 12). In the words of Torras, it would seem that the architrave "is suffering" under the weight of the entablature and is bending under the flexure force adopting the shape of the deflection, that is in terms of structural calculation. There can be no doubt that this is a re-edition of a beam of equal strength as conceived by Torras. Even the constructive longitudinal section (Figure 13) brings to mind his patent of 1876 in some way: the compression region of the beam is made up of various thicknesses of brick and underneath two strips of twisted steel, embedded in mortar, are placed following a slight parabola. The bricks work in compression, while the steel works in tension and the mortar wraps around the tie rod, giving it an effective bond.

Here for all to see, other than a beam of equal strength, is Gaudí's acknowledgment to the Greek order of mimetic transfiguration. That is, in ancient Greek mimesis (μίμησις) conveyed not only

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the imitation of nature but included the ability to give life to what is represented through profound understanding of its essence and how it is perceived by man (Rykwert 1999, 170–209). In architecture, mimesis was used to correct temples optically, but also for the development of new forms which, in turn, always summon up other phenomena or objects of nature as if poetic metaphors: the fluted shaft that moulds the sunlight around the cylinder that brings to mind an axe shaving the bark of a tree trunk, the echinus mouldings of the Doric capital that evoke the shell of the sea urchin, but also Greek ceramic bowls... In the same way Gaudí transforms a technical form (a beam) into an artistic form (a warped "potbellied" beam). An artistic form that calls for the "suffering" of the architrave that must withstand weight as a punishment, a weight so heavy that it also fatally deforms the capital's echinus until the shaft looks as if it is about to split the abacus. Here again are Schopenhauer and Carl Gottlieb Wilhelm Bötticher (1806–89) with their formulation on the intimate relationship between the *Kernform* (kernel form or technical form) and the *Kunstform* (art form) that was so influential on the theory of architecture in the 1800s (Frampton 1995, 82–84; Mallgrave 2005, 108–113).

Moving on to the hypostyle hall, Gaudí eliminates several columns to make more room for the market place. Thus, from a structural point of view, the study of the mixed beams that allow the removal of columns of the hall is nothing other than relocating the problem of the architrave to allow for a three times wider span. A complex beam, close cousin to the beam of equal strength (made up of upper arches of bricks in wads, taut underneath by tie rods embedded in ribbed mortar) that gives for a wider span while eliminating columns. And, magically, the visual effect produced when looking up, as Àngel Toldrà Viazo's photograph shows (Figure 14), is of four loose ribs that cross each other where there ought to be a column, substituted by an exaggerated

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keystone decorated with ceramics by his assistant Josep Maria Jujol. In fact, the structure is only suggested, and Gaudí chose the visual instability of that what hangs loosely and at the same time remains tense.

On the ceilings of the two pavilions at the entrance of Park Güell, built between 1903 and 1905 (Aguado et al. 2002), the two floors of the janitor's pavilion have deliberately expressive intrados ceilings (Figure 15). Like a whale's skeleton, ribbed beams, visible and sinuous, support the floor. And in the same way as in the architrave of the hypostyle hall its profile is not fortuitous, here again can be found the umpteenth reinterpretation of the beam of equal strength, in this case, from the deflection of a doubly built-in beam. Inside the mass of lime mortar a corkscrew-shaped steel strip follows the sinuous profile of the beam and embeds itself into the walls. In this constructive solution, besides developing a tensile construction, Gaudí experiments with the possibilities offered by a new technique with reinforced concrete that had been brought to Catalonia a few years earlier by Francesc Macià and Claudi Duran (Martín-Nieva 2000; Grima et al. 2011, 643–653; Graus 2012, 412–426; Grima et al. 2013).

It is difficult, having come so far, not to succumb to the temptation of mentioning the Teatre del Patronat Obrer (1908) by Josep Maria Jujol i Gibert (1879–1949) (Lahuerta 1998, 36–41), known today as the Metropol Theatre, in Tarragona. In the semi basement area, the part submerged in the sea, in the words of Josep Llinàs, the architect of its last restoration (Llinàs 1996), framed blue "potbellied" ceilings, foam like in appearance, fashioned by two visible flat iron bars that sluggishly pull at the ceiling can be seen (Figure 16). Here, visible to the naked eye is the taut element hidden in the mortar beneath the Gaudinian mosaic of the hypostyle hall of the Park Güell. Jujol exposes the thinness of the iron plate and its great strength, tensed like the hoops of a wine barrel.

Conclusion

All the efforts described above seemed geared towards a search for the “beauty of the beam”. An oxymoron like beauty with its profound contradiction: the disturbing “potbellied” form suggested by the deflection caused by the weight, at the same time, guarantees the mathematical solution for a perfect beam based on forms that imitate a parabola. If the floor beam of equal strength of Torras’s patent of 1876 was the reflection of pure calculus in search of a just structure which in turn was the sincere expression of the strength of the material to be conquered, years later, first Gaudí’s expressive universe from 1903 poetically transfigured the beam of equal strength to graft itself with the mimetic gestures of ancient Greece. And later on, in 1908 Jujol also sublimely transfigures it into a simple fisherman’s net.

(Translation: Rico Rosell)

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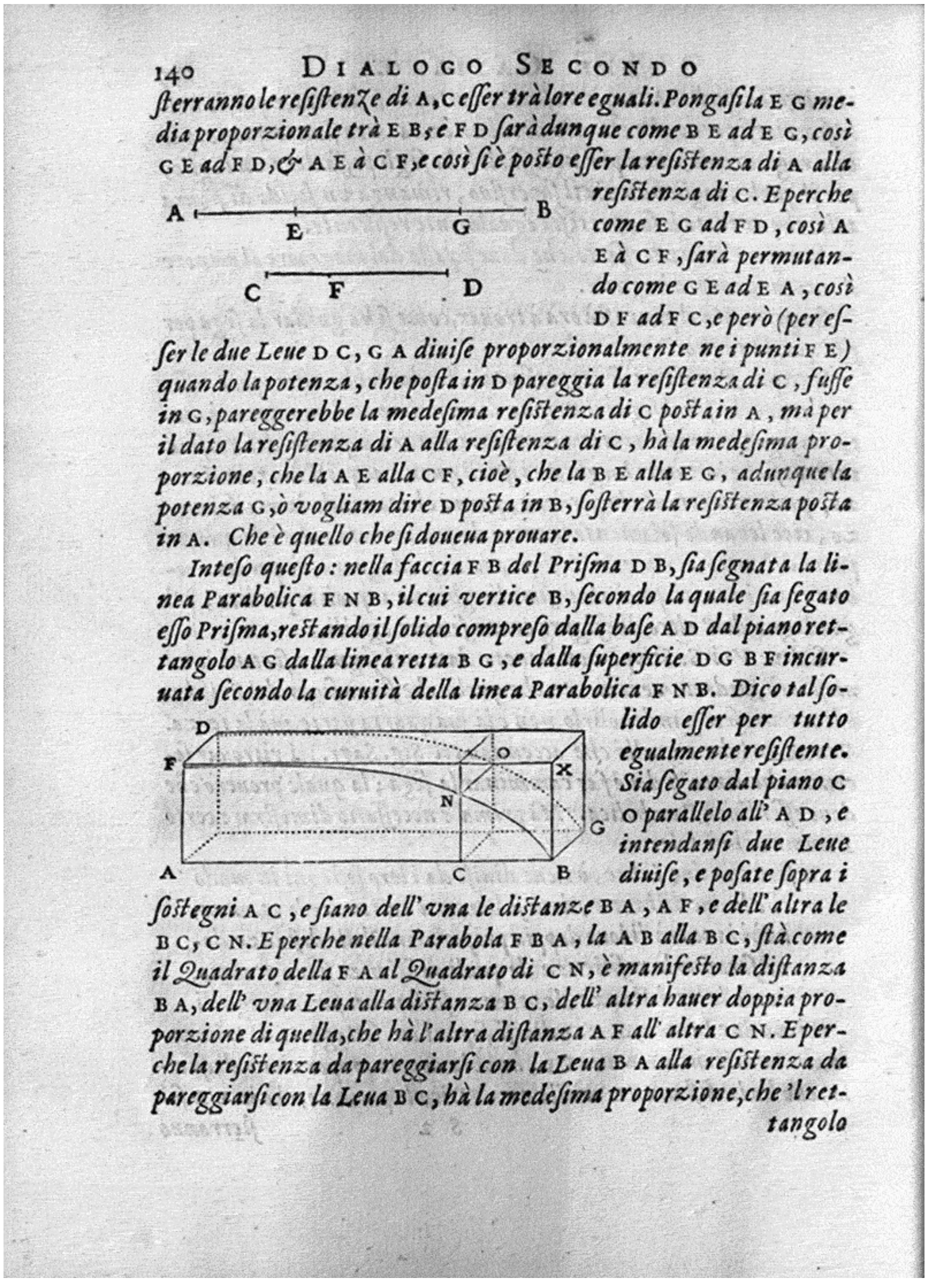
Figure 1. Page from the second day of the *Discorsi* (1638) where Galileo raises the concept of the beam of equal strength [(Galilei 1638) E-rara.ch, ETH-Bibliothek].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ſterranno le reſiſtenze di A, C eſſer trà lore eguali. Pongaſi la E G media proporzionale trà E B, e F D ſarà dunque come B E ad E G, così G E ad F D, & A E à C F, e così ſi è poſto eſſer la reſiſtenza di A alla reſiſtenza di C. E perche come E G ad F D, così A E à C F, ſarà permutando come G E ad E A, così D F ad F C, e però (per eſſer le due Leue D C, G A diuiſe proporzionalmente ne i punti F E) quando la potenza, che poſta in D pareggia la reſiſtenza di C, fuſſe in G, pareggerebbe la medeſima reſiſtenza di C poſta in A, mà per il dato la reſiſtenza di A alla reſiſtenza di C, hà la medeſima proporzione, che la A E alla C F, cioè, che la B E alla E G, adunque la potenza G, ò vogliam dire D poſta in B, ſoſterrà la reſiſtenza poſta in A. Che è quello che ſi doueua prouare.

Inteſo queſto: nella faccia F B del Priſma D B, ſia ſegnata la linea Parabolica F N B, il cui vertice B, ſecondo la quale ſia ſegato eſſo Priſma, reſtando il ſolido compreſo dalla baſe A D dal piano rettangolo A G dalla linea retta B G, e dalla ſuperficie D G B F incuruata ſecondo la curuità della linea Parabolica F N B. Dico tal ſolido eſſer per tutto egualmente reſiſtente. Sia ſegato dal piano C O parallelo all' A D, e intendanſi due Leue diuiſe, e poſate ſopra i ſoſtegni A C, e ſiano dell' vna le diſtanze B A, A F, e dell' altra le B C, C N. E perche nella Parabola F B A, la A B alla B C, ſtà come il Quadrato della F A al Quadrato di C N, è manifeſto la diſtanza B A, dell' vna Leua alla diſtanza B C, dell' altra hauer doppia proporzione di quella, che hà l'altra diſtanza A F all' altra C N. E perche la reſiſtenza da pareggiarſi con la Leua B A alla reſiſtenza da pareggiarſi con la Leua B C, hà la medeſima proporzione, che 'l rettangolo

Figure 2. The architect Joan Torras Guardiola (1827–1910) in 1891 [Collection A. Feliu-Torras].

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Figure 3. Joan Torras's floor (4 m span), Barcelona, 1876 [Authors's drawing, 2012].

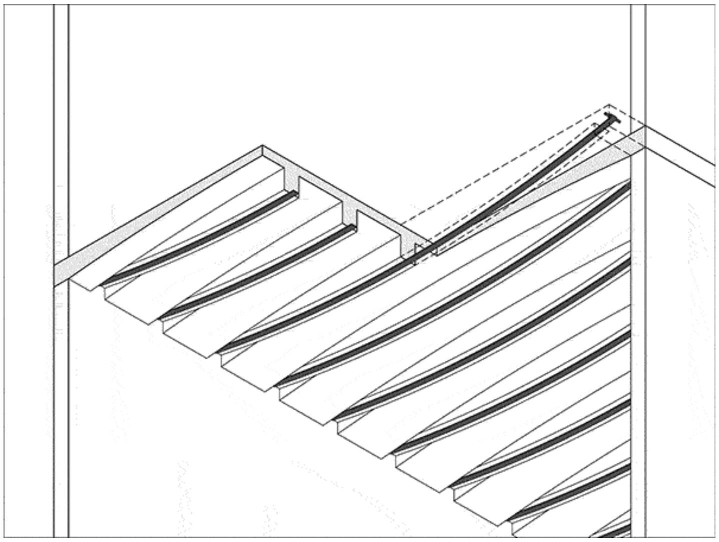

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Figure 4. Two beams of equal strength (1,37 m span) from the experimental research using cast iron, by William Fairbairn and Eaton Hodgkinson (1831) [(Fairbairn 1854) COAC Library, Barcelona].

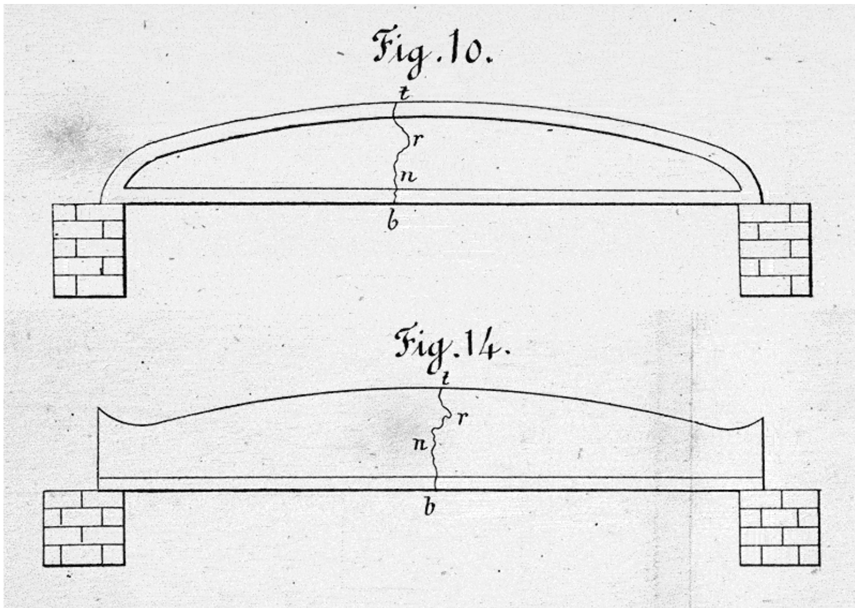

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Figure 5. Joan Torras's patent "*A new system of hanging beams and floors*" (1876) for a 4 m span floor [AH-OEPM, Madrid].

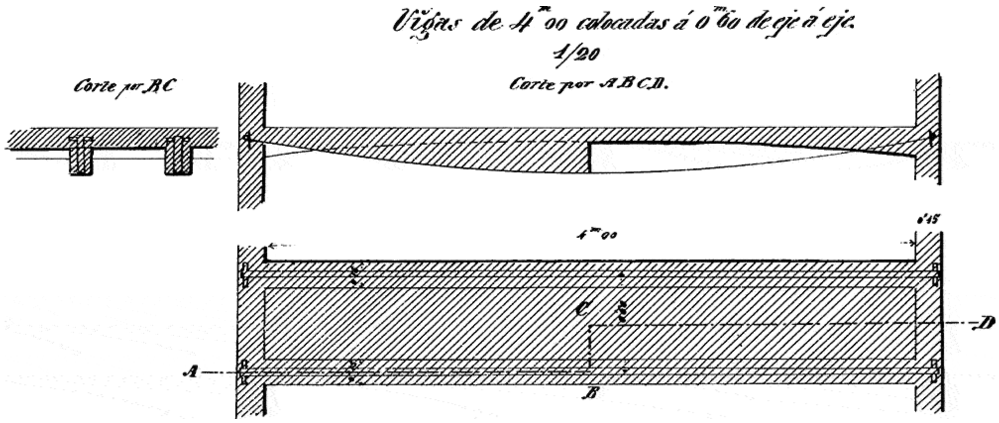

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Figure 6. Central hall of Elies Rogent's Palau de la Indústria for Barcelona's Universal Exhibition of 1888, under construction [*La Exposición*, 20/4/1888. Biblioteca de Catalunya, Barcelona].

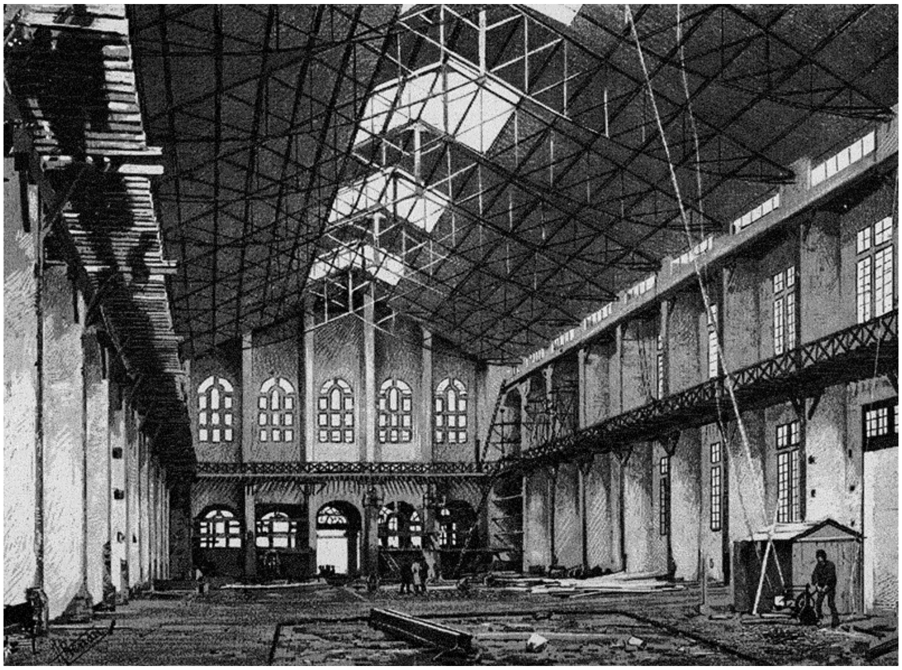

Figure 7. Joan Torras's "fly wing" roof trusses (30 m span) for the central hall of the Palau de la Indústria (1888) [H 101 F/6/786, Arxiu Històric–COAC, Barcelona].

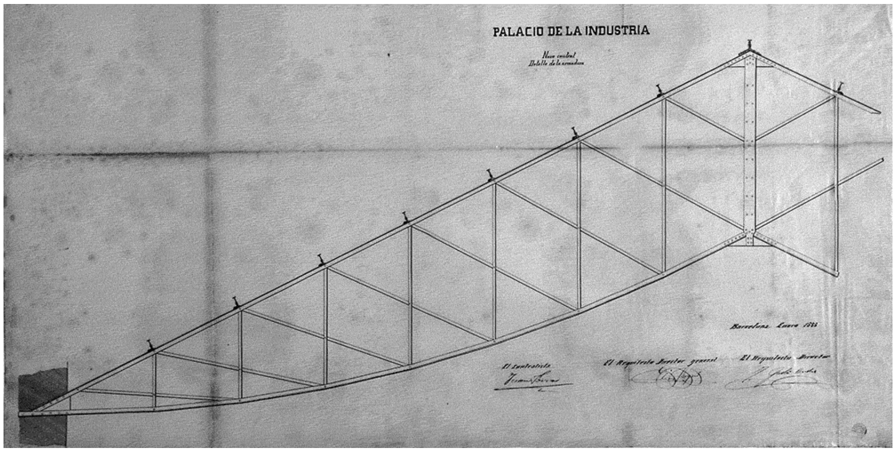

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Figure 8. Similarities between the beam of equal strength and the constant-force gable truss, exemplified in "fly wing" parabolic truss by Joan Torras [Authors's drawing, 2012].

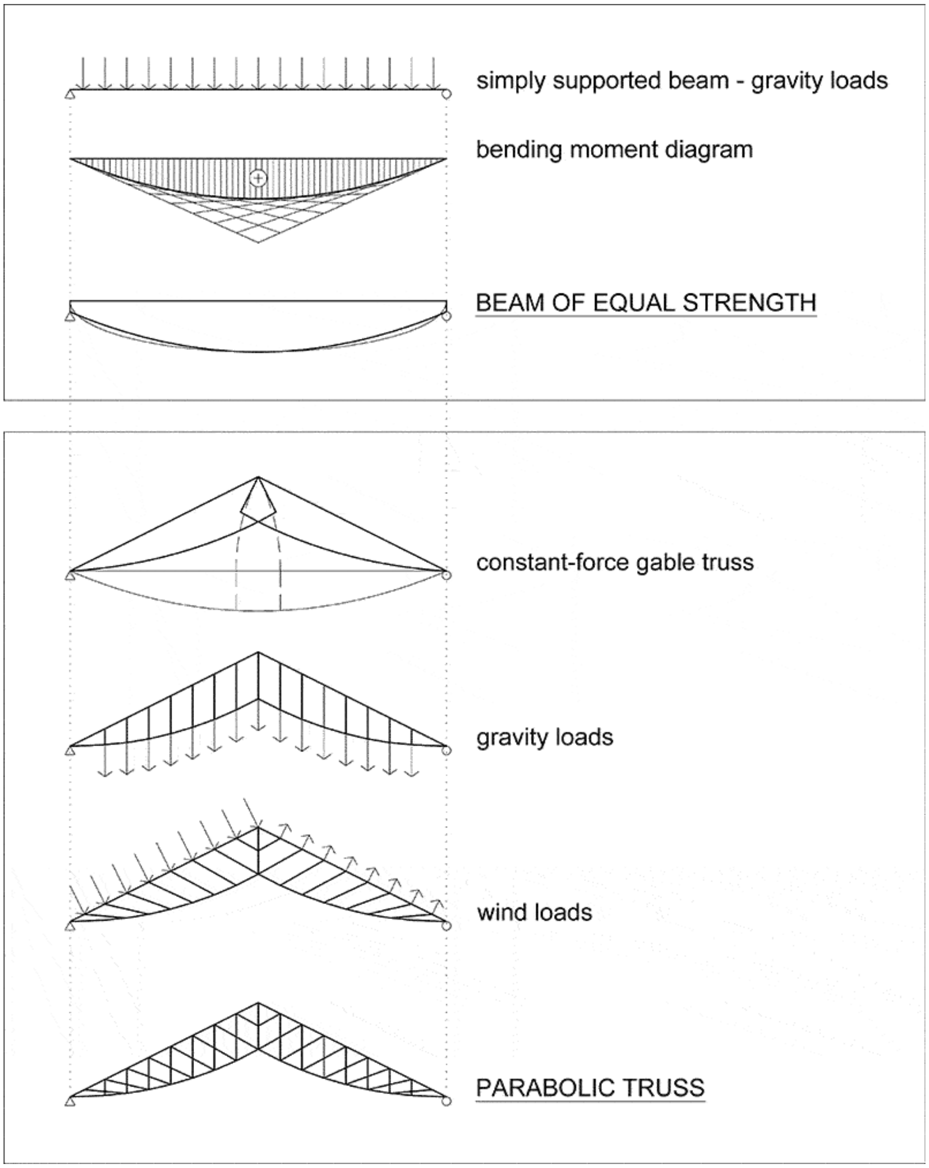

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Figure 9. Reinforced concrete bridge (15 m span) over the Selke at Alexisbad (Germany) by Max Möller (1896) [(Drenckhahn 1904, [32]) Copyright Universitaetsbibliothek Braunschweig].

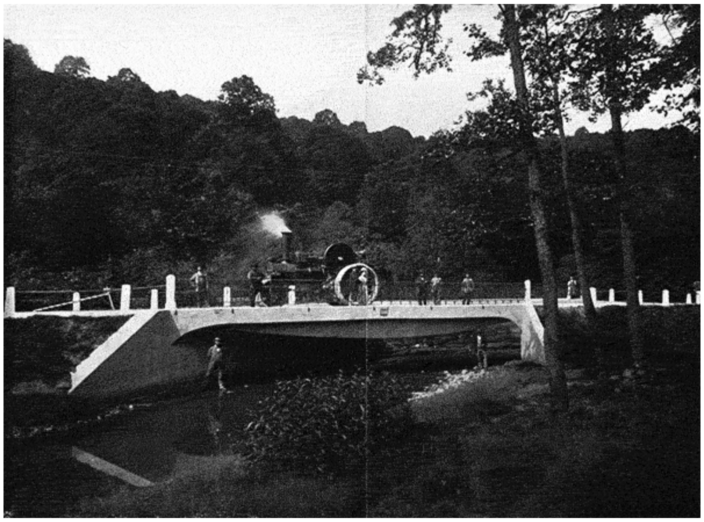

Figure 10. Constant-force gable trusses (23,60 m span) in the *Magazzini Generali* of Chiasso (Switzerland) by Robert Maillart (1924) [ETH–Bibliothek Zürich, Bildarchiv/Robert Maillart-Archiv].

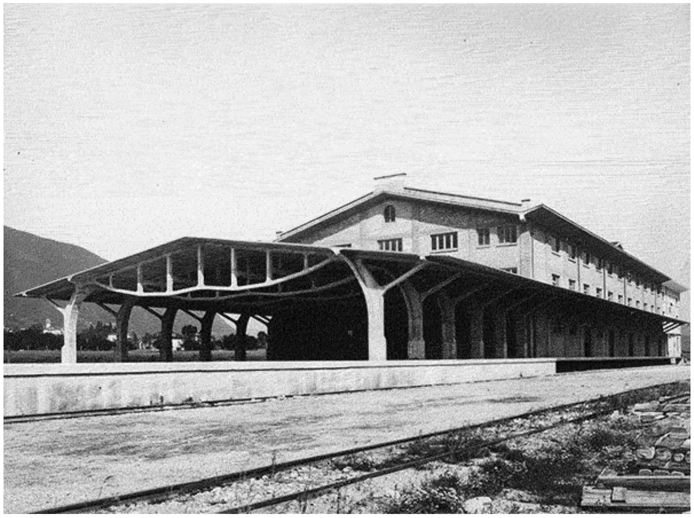

Figure 11. Flooring proposed by Rafael Guastavino in the United States of America [(Guastavino, 1893, 103–104) COAC Library, Barcelona].

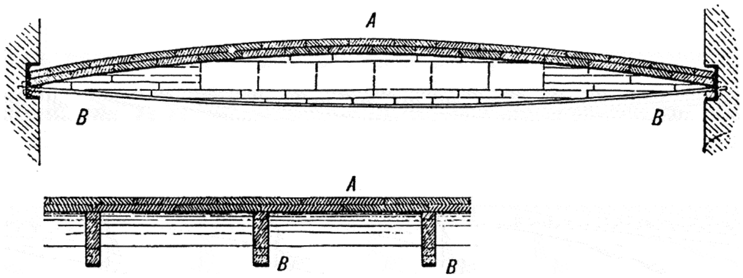

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Figure 12. The hypostyle hall under construction in Barcelona's Park Güell by Antoni Gaudí (ca. 1906), with its prefabricated architrave's on the columns [Postcard. Authors's collection].

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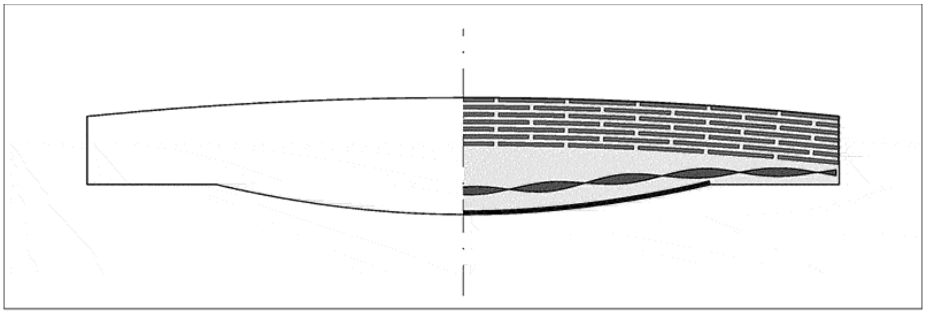
Figure 13. Front elevation and longitudinal section of the architrave (2 m span) where Gaudí exaggeratedly deflects the expressiveness of the Doric capital's echinus so that the architrave also deflects to approximate the shape of a beam of equal strength (ca. 1906) [Authors's drawing, 2012].



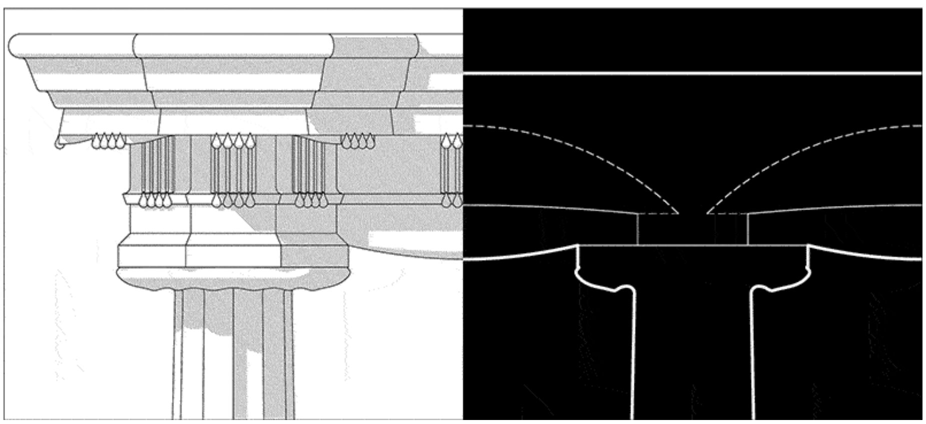


Figure 14. Inside the hypostyle hall where Gaudí has eliminated a column using a beam of equal strength (6 m span) camouflaged by an exaggerated keystone (ca. 1907-8) [Postcard by Angel Toldrà Viazo, photographer. Authors's collection].

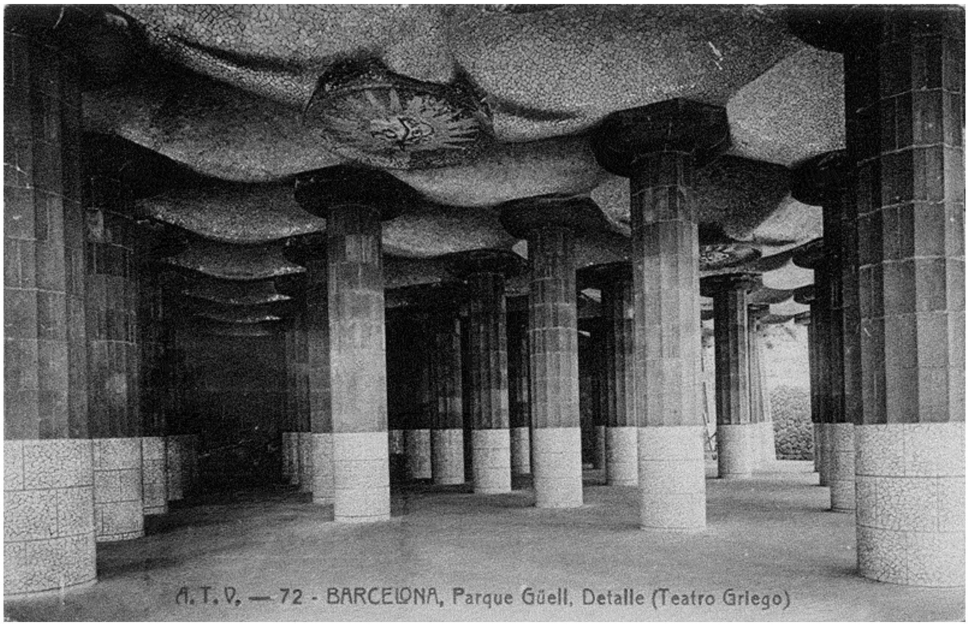


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Figure 15. Ribbed floor (3,77 m span) of one of the entrance pavilions of Barcelona's Park Güell by Gaudí (ca. 1903-5), where the curve and counter-curve evoke and exaggerate the deflection of a beam with fixed end supports [Authors's drawing, 2012].

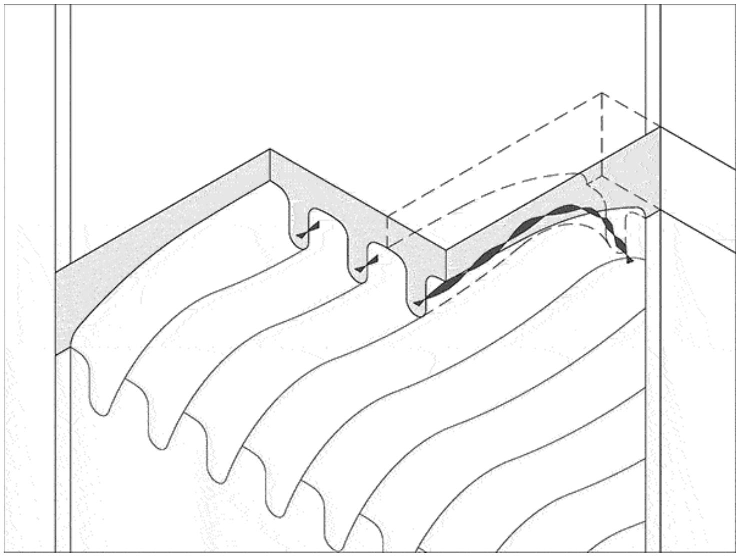

Figure 16. General view of a single frame (3 m span) from the ceiling of the Metropol Theatre in Tarragona by Josep Maria Jujol (1908). The frame is being held up by flat iron bars stretching diagonally across them like beams of equal strength [Authors's drawing, 2012].