The Writings of Belgian Engineer Arthur Vierendeel (1852-1940): Homo Universalis or Contemporary Propagandist?

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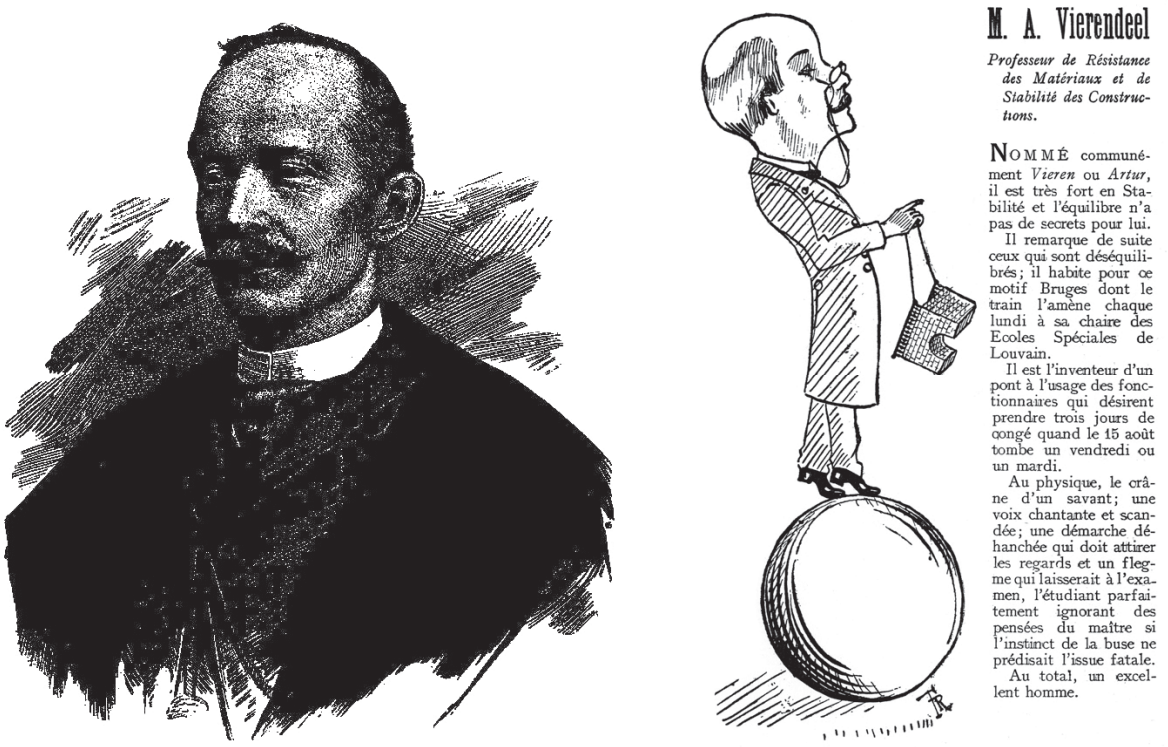
ABSTRACT: During the last decade of the nineteenth century, Belgian engineer and professor Arthur Vierendeel - mostly known for the Vierendeel, a frame without diagonal rigidifying elements - published a series of books in which he expounded his views on the use of steel in architecture and engineering. Vierendeel described the structural possibilities of constructing in iron, and also theorized how this 'new' material should capture its own architectural style. Structural aesthetics is derived from rivets, proportions, tie rods, columns and covering strips whereas auxiliary aesthetics can be created through adding ceramics, other metals and decorative painting. Formal issues had to surpass structural considerations, or in Vierendeel's words: "Pour les constructions métalliques les dimensions doivent être déterminées à priori par des considérations esthétiques et qu'après seulement il y a lieu de recourir à la formule mathématique."

INTRODUCTION

Belgian engineer Arthur Vierendeel (1852-1940) is best remembered for the Vierendeel, a construction similar to a truss but with rigid joints instead of the rigidifying diagonals. Vierendeel was however not only occupied with structural mechanics, but with many fields of engineering and architecture. His prolific writings and the fact that he wrote in French made his ideas and theories very accessible at the time. Next to his 8 part handbook *Cours de stabilité des constructions*, his books on the Vierendeel and other aspects of engineering, Vierendeel wrote 2 books and gave many lectures on the use of iron in architecture. They represent his view on how this 'new' material was to be used in architecture and, more importantly, which ornamentation could go with it.
The main question this paper focuses on, is if Vierendeel was a homo universalis combining his scientific and artistic knowledge, or whether he was simply trying to turn iron into an acceptable building material. Its use in architecture had been the subject of discussions by architects, engineers, art historians, philosophers and writers during the entire nineteenth century. Vierendeel's plea was published at a turning point. On the one hand iron had already been thoroughly discussed aesthetically, on the other hand the twentieth century was just around the corner with the Art Nouveau and Adolf Loos' *Ornament und Verbrechen* as two examples of more modern approaches of the same discussion. (Note: In this text iron will be used as a general term for cast iron, wrought iron and steel.)

JULES ARTHUR VIERENDEEL

Jules Arthur Meunier was born in Leuven on the 10th of April 1852 as the son of Josephine Meunier. After the death of his father, his mother married locksmith Pierre Jean Vierendeel in 1857 and Arthur Meunier took over his stepfather's name. He was raised in Geraardsbergen, 40 km east of Brussels, and in spite of financial difficulties Vierendeel attended the Ecoles Spéciales of the Catholic University of Leuven. In 1874 he got, with great distinction, the degree of *ingénieur des arts, des manufactures, du génie civil et des mines*.



M. A. Vierendeel

Professeur de Résistanee des Matériaux et de Stabilité des Constructions.

NOMMÉ communément *Vieren* ou *Artur*, il est très fort en Stabilité et l'équilibre n'a pas de secrets pour lui.

Il remarque de suite ceux qui sont déséquilibrés; il habite pour ce motif Bruges dont le train l'amène chaque lundi à sa chaire des Ecoles Spéciales de Louvain.

Il est l'inventeur d'un pont à l'usage des fonctionnaires qui désirent prendre trois jours de congé quand le 15 août tombe un vendredi ou un mardi.

Au physique, le crâne d'un savant; une voix chantante et scandée; une démarche déhanchée qui doit attirer les regards et un flegme qui laisserait à l'examen, l'étudiant parfaitement ignorant des pensées du maître si l'instinct de la buse ne prédisait l'issue fatale.

Au total, un excellent homme.

Figure 1: Arthur Vierendeel; (Radelet-de Grave 2003, p. 84 and Redan 1913, p. 49)

Vierendeel started his career in the building industry. As a commissioner of the Ateliers de La Louvière where he worked for ten years (1876-1885) he was among other things responsible for the construction of the Royal Circus in Brussels, one of the first iron frameworks in Belgium. This structure caused him a lot of worries and shows at the same time his perseverance. The owners and the press were convinced that the light structure would never be sufficiently supportive, but Vierendeel pursued and did not change his plans. As a consequence a committee of inquiry had to be installed. Its members couldn't find any errors in the calculations, still they also took the owner's view. Only after an ultimate test with a regiment of grenadiers ordered by the minister, animadversion was put to a stop. The building was demolished in the middle of the twentieth century due to changed opinions on style and replaced by a new one.
In 1885 Vierendeel was named head-engineer-director of the technical services of the province of West-Flanders. In this respect he was mostly responsible for 2 271 km of road construction. After the First World War, which had been very destructive for the coastal province, he played an important role in the reconstruction of the heavily devastated front.

Professor at the Catholic University of Leuven

Four years after Vierendeel started working in West-Flanders, his preceptor Louis Cousin asked him to be his successor for his course on structural mechanics. When Vierendeel began teaching, his architectural work that concluded the covering of the railway station of Kortrijk and the tower of the church of Dadizele, both in West-Flanders, came to a standstill. From then on he would only construct bridges, pylons and other civil works.
Numerous articles state that Vierendeel has also taught history of architecture, but this is not confirmed by the course programmes from the time he was professor. Architectural history was successively taught by architect and minister Joris Helleputte (1852-1925) until 1910 and later on by canon and architect-restorer Raymond Lemaire (1878-1954).

The Vierendeel

Though the form is already present in his design for the Dadizele church, Vierendeel starts defending the idea of a truss without diagonals in 1895. The so-called Vierendeel frame is a series of rectangular frames which achieves stability by the rigid connection of the vertical web members to the top and bottom chord. Contrary to the typical pin-connected truss the Vierendeel transfers shear from the chords by bending moments and finally by bending moments in the vertical webs. As a result, all members are combined stress members in which axial, shear and bending stresses exist (Wickersheimer 1976, p. 54). It was mostly used in bridges but could also be seen in structures requiring rectangular openings for practical or technical purposes, e.g. in trains and skyscrapers.
As a jack-of-all-trades Vierendeel also wrote on soil mechanics, electromagnetism and aircraft building (never published) and he derived a general formula to explain buckling failure.

THE 1889 WORLD FAIR IN PARIS

Vierendeel had just begun teaching when he started writing extensively on all kinds of subjects related to architecture and engineering. His first book on architecture *L'architecture métallique au XIX^e siècle et l'Exposition de 1889, à Paris* was published in 1890. Mainly by looking at the world fair that was organized the year before in Paris it covered all architectural aspects of building in iron. In the introduction Vierendeel admitted that his statements were to be argued since the subject had not yet been up for much consideration.

> L'Exposition de cette année à Paris, où cette architecture joue un rôle prépondérant, était une occasion toute naturelle de communiquer au public le résultat de nos études sur cet intéressant sujet. […] Nous nous sommes enhardi à donner quelques règles essentiels déduites de l'observation et qui, d'après nous, doivent dominer toute l'architectonique du métal. […] Le sujet est neuf, très obscur encore, la discussion seule peut l'élucider et le préciser ; nous la désirons de tous nos vœux. (Vierendeel 1890, pp. 5-6)

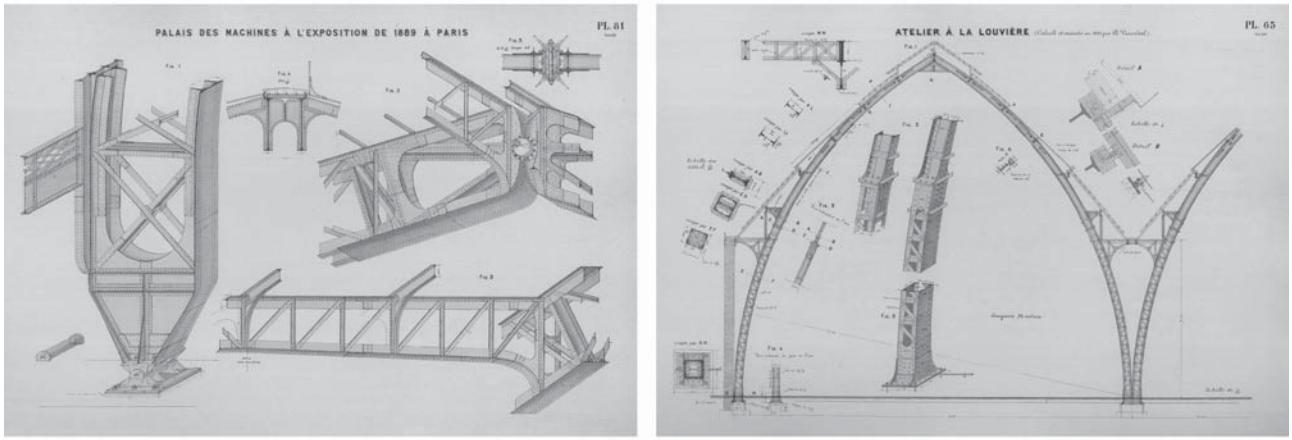


Figure 2: The Palais des Machines for the 1889 world fair in Paris; (Vierendeel 1902, plate 81) and the Atelier in La Louvière; (Vierendeel 1902, plate 65)

The 1889 world fair in Paris had indeed been exceptional for the use of iron in architecture. Not only had Gustave Eiffel (1832-1923) been able to erect the highest construction ever. Also the largest wide-spanned iron-framed structure was created at the Galerie des Machines. For Vierendeel these buildings proved the unlimited possibilities of iron.

> L'Exposition de Paris se distingue surtout par les immenses constructions métalliques qui y ont été élevées comme par enchantement. […] Qu'est-ce qui est encore impossible à l'homme comme construction dans les limites de la planète qu'il habite? […] On dirait que pour le métal, fer ou acier, l'attraction terrestre n'existe pas, il la dédaigne, il s'élance et plane en dépit de le pesanteur ; il la combat et la vainc non au moyen de colonnes mais par l'énergie latente qui anime tout son être. Les encorbellements les plus hardis, les porte-à-faux les plus prestigieux se réalisent avec aisance là où le métal intervient ; en un mot le métal se passe du point d'appui, il fait fi de la colonne. (Vierendeel 1890, pp. 7-9)

Vierendeel was not altogether positive on what he saw in Paris. He openly criticized the Palais des Machines which he found badly lit due to a wrong design of the archs and badly proportioned in its entirety and in its details.

> Il est à remarquer qu'une construction peut être grande et cependant ne pas produire un effet de grandeur, tel est le cas pour le Palais des Machines. Par contre une construction peut être petite comme dimensions absolues et cependant donner l'impression de la grandeur, de la majesté, telles sont les belles constructions grecques. […] Toute est une question de proportions. (Vierendeel 1890, p. 28)

As an alternative solution Vierendeel referred to Palladio's formula to obtain, for a given span, three proportional heights for a building. With a vaulted ceiling, Palladio stated the room's height should be equal to the arithmetic, geometric or harmonic mean between length and width. In a room with a flat ceiling the height should be equal to the width (Palladio 1570, pp. 53-54). For the Palais des Machines these equations give three corresponding heights, all exceeding the actual size.
Vierendeel's design for a factory building in La Louvière (1880-1881) had already solved these issues. Though some of the reasons had a practical nature (the hall was used to manufacture bridges with heights up to 12 m), the proportional aspects are more concisely applied.

> Pour un simple atelier on n'a évidemment pas cherché à faire de l'esthétique ; cependant, sans l'avoir voulu, cette ossature présente des qualités qui attirent l'attention. Les proportions d'ensemble sont heureuses, l'ogive en tiers-point réalise entre la largeur et la hauteur du vaisseau une relation qui plaît beaucoup. La forme en caisson du pied des arcs, caisson dont les dimensions sont modérées puisque pour

> 7 mètres de hauteur elles sont de 300 sur 317 millimètres, leur donne un aspect de svelte robustesse ; cet aspect persiste dans les parties hautes où l'arc devient plus léger, ce qui est conforme à notre sentiment, il y passe du caisson à la forme en simple double té et les dimensions de ce double té sont bien pondérées : pour une largeur de 150 millimètres la hauteur est de 300 seulement. (Vierendeel 1902, p. 198)

Analogous phenomena

When talking about analogous phenomena in history, Vierendeel was convinced that architecture in iron would be a worthy equivalent of the Gothic that enlightened the Middle Ages from the twelfth century onwards. He elaborated the ideas of Viollet-Le-Duc, though he used steel not only as a linear element but also as a full building component to make walls and ceilings with a high fireproof level.
The plea of architect, art historian and archaeologist Karl Gottlieb Wilhelm Bötticher (1806-1889) was similar. It went back to his lecture *Das Prinzip der Hellenischen und Germanischen Bauweise hinsichtlich der Übertraging in die Bauweise unserer Tage* of 1846. Bötticher was convinced that iron represented the dawn of a new style. The system of stone beams and arch vaults had completely exhausted the constructional possibilities of stone. Iron was to be the third step in the history of construction.
Finding proper ornamentation for steel is one of the crucial points in Vierendeel's plea. He drew up the characteristic trademark that uses steel's structural components: the form and positioning (in patterns) of rivets, joint plates, assembly structures and trellis. Furthermore, he adds the possibilities of making columns in cast iron (the most sculptural form of steel) and the application of paint and ceramics to both protect and embellish the structural layer.
Being aware of a lot of disadvantages attributed to metal structures, Vierendeel tries to refute them one by one. He offers elegant and technical solutions for problems in the field of building physics and building technology (e.g. cooling and heating in summer and winter, rust and brittle cracks and fire risk).

Architects vs engineers

Striking is Vierendeel's criticism against the dominant role of the engineer - himself only having received an engineering education - when designing buildings in steel. Nevertheless he also states that till that day engineers have been the only designers who have tried to capture, not with any real success, the architectural form of this so-called new material - having a slight advantage by not having received education on architectural history and 'archaeological' forms.
Vierendeel concluded L'architecture métallique au XIXe siècle et l'Exposition de 1889, à Paris by stating:

> Surtout nous avons itérativement insisté sur ce point que pour les constructions métalliques les dimensions d'ensemble, en vue de pondérer et d'harmoniser les masses, doivent être déterminées à priori par des considérations esthétiques et qu'après seulement il y a lieu de recourir à la formule mathématique pour se fixer sur la question de résistance. (Vierendeel 1890, pp. 96-97)

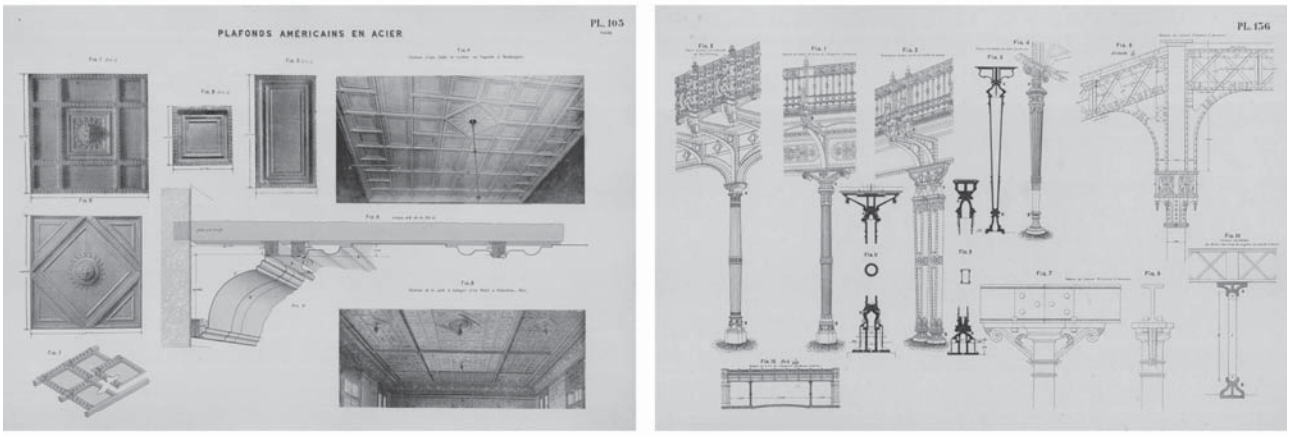


Figure 3: American ceilings in steel; (Vierendeel 1902, plate 103) and cast iron columns; (Vierendeel 1902, plate 136)

VIERENDEEL'S OPUS MAGNUM *LA CONSTRUCTION ARCHITECTURALE EN FONTE, FER ET ACIER*

With the advent of the twentieth century Vierendeel published his opus magnum *La construction architecturale en fonte, fer et acier*, a book containing 899 pages and 130 plates and which was awarded the Prix du Roi in 1896. Most of the plates illustrated important iron structures of the nineteenth century though the last plates illustrated the architectural role of iron by using it as a flat element to finish and decorate spaces instead of using it as a linear element. Vierendeel mostly expounded the views of his previous book of 1890 (the dates on his drafts for the book showed that he already started writing chapters on aesthetic aspects in 1890).

The book covered all aspects of building in iron: a brief history, 200 pages on the most important iron buildings till then, the combination of iron with glass and concrete, paint to preserve iron, the influence of temperature and weather conditions on iron constructions, computation rules and three chapters on respectively perturbing effects of light, perturbing effects of lines and the aesthetic qualities of iron constructions. The latter three will be described hereafter.

Perturbing effects of light and lines

After the Greek philosophers one had to wait until the nineteenth century until one started examining optical illusions again. In 1826, psychologist Johannes Peter Müller (1801-1858) wrote two books about visual illusions. In 1854, another psychologist J. J. Oppel continued were Müller left off. He published a paper with ten pages about line illusions. The famous and non cross-cultural Müller-Lyer illusion, in which the orientation of arrowheads makes one line segment look longer than another, was introduced and twelve theories were made to explain the illusion. Other line illusions to come about include the Hering illusion and the Wundt illusion (two vertical lines are both straight, but they look as if they are bowing respectively outwards and inwards due to a lined pattern on the background), the Poggendorff illusion and the Zöllner illusion. All were discovered in the 1860s and demonstrate how lines can seem to be distorted by their background.
Vierendeel was probably aware of these theories and used these findings in his chapters on the perturbing effects of light and lines. He was furthermore one of the few writers to give a profound analysis of the massless characteristic of iron structures.

> Il est un phénomène que tous nous avons plus d'une fois été dans le cas de constater : les membrures d'une construction métallique se présentent en général mal dans la lumière, elles manquent de fermeté dans les lignes, de décision dans l'allure, même plus, quand on se déplace en les regardant on dirait qu'elles bougent et il est à remarquer que cette sensation de mouvement est très réelle, ce n'est pas une illusion de notre œil, c'est un phénomène physique. [...] La cause de tout ce mal est la lumière, c'est elle qui rompt les membrures métalliques et leur enlève cette stabilité d'aspect qui est une des conditions fondamentales de toute beauté architecturale. (Vierendeel 1902, p. 567)

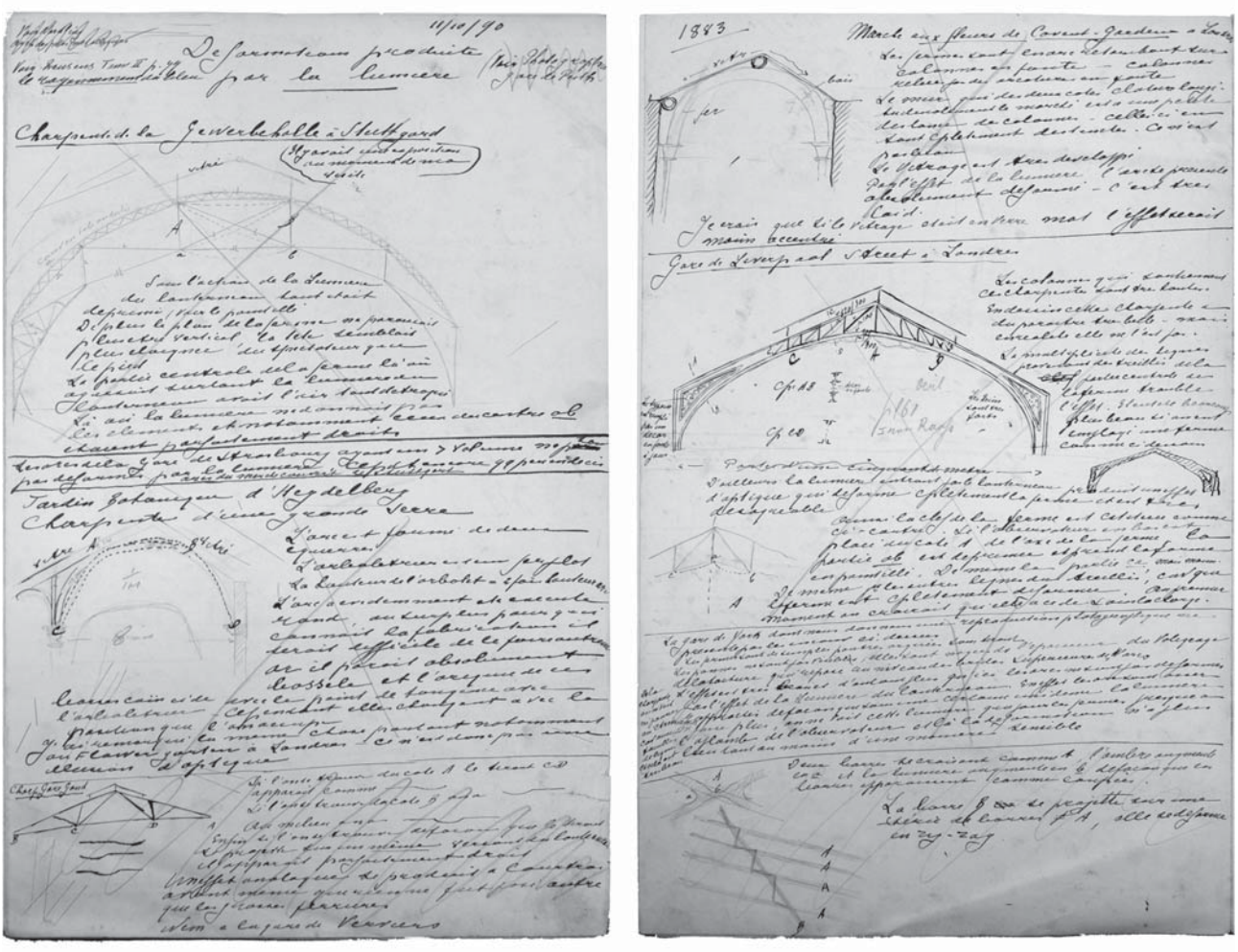


Figure 4: Vierendeel's draft and sketches for his chapter on perturbing effects of light, dated 11th of October 1890; (Tabularium Catholic University of Leuven, Vierendeel P141/2)

He stated that, due to the slender form of its composing elements, light can easily deform these, thus creating a structure with an awkward look. Referring to Greek builders, Vierendeel wrote that "ils abandonnèrent la ligne droite et la remplacèrent partout par une courbe calculée de façon à neutraliser l'effet déformateur de la lumière."(Vierendeel 1902, p. 568) When one (linear) element is behind another or vice versa and these elements do not intersect, their shadows will deform as such: the common shadow becomes weaker whereas their adjacent shadows become stronger, giving "une forme en zig-zag des plus laide *(sic)*" as can be seen in the railway station of Budapest (Vierendeel 1902, p. 570). Similar effects existed in the railway station of Ghent. Vierendeel has 4 ways to remedy: (1) avoid using slender elements - "Là donc où l'on désire produire un effet architectural on ne recourra pas aux fermes à tirants multiples: fermes Polonceau et dérivées."; (2) avoid using skylight since this light is the most responsible for disordering frames; (3) try to find the right colour for the window-panes and (4) use mat glass when necessary. (Vierendeel 1902, pp. 578-586)

Aesthetic characteristics of iron constructions

In the chapter on the aesthetics of iron constructions Vierendeel examined the aesthetic possibilities that could be attributed to iron. This linear issue, though in conflict with some of his other arguments, is important to him since "pour une façade rien de mieux en règle générale au point de vue constructif et esthétique qu'une bonne maçonnerie de briques ou de pierres naturelles." (Vierendeel 1902, p. 774)
Proportions are of major importance for iron since it is the only material that can keep its structural properties throughout various appearances.

> Un pillier ou un arc en maçonnerie de dimensions données n'a qu'une seule résistance bien déterminée, tandis qu'un sommier en fer, en forme de caisson par exemple, ayant une largeur l et une hauteur h, peut présenter à égalité de sécurité les résistances les plus variées, depuis les moindres jusqu'aux plus élevées, cela d'après les épaisseurs des tôles et fers constituant le caisson. (Vierendeel 1902, p. 780)

In this connection we read once more Vierendeel's idea of mass against void, that was already mentioned when discussing the Palais des Machines. Also the Eiffel Tower would now serve as a grateful scapegoat.

> Tout le monde le sait, le treillis le plus ouvert, le plus évidé est le plus économique, mais là où l'on veut réaliser le beau il faut quelquefois savoir sacrifier l'économie. […] Il faut que les vides ne prennent pas trop d'importance par rapport aux pleins. […] Si la Tour Eiffel vue de près produit un effet qui n'est pas toujours des plus heureux, c'est précisément parce qu'on y a trop multiplié les organes de petits échantillons ; ils embrouillent dans la perspective, ils empâtent dans la lumière, c'est un magma vertigineux, l'œil s'y perd, aucune ligne saillante ne se présente qui puisse lui servir de fil d'Ariane à travers ce dédale de ferrailles. […] La Tour Eiffel est une tour en minces treillis, c'est la grosse faute esthétique qui a été commise par ses constructeurs ; ce sont ses treillis qui diminuent le cachet architectural de la tour et justifient en grande partie toutes les critiques dont elle a été l'objet de la part de beaucoup d'architectes et artistes.(Vierendeel 1902, pp. 781-786)

This proposition on the morbid growth of trellis automatically lead Vierendeel to support his own patented work, the Vierendeel.

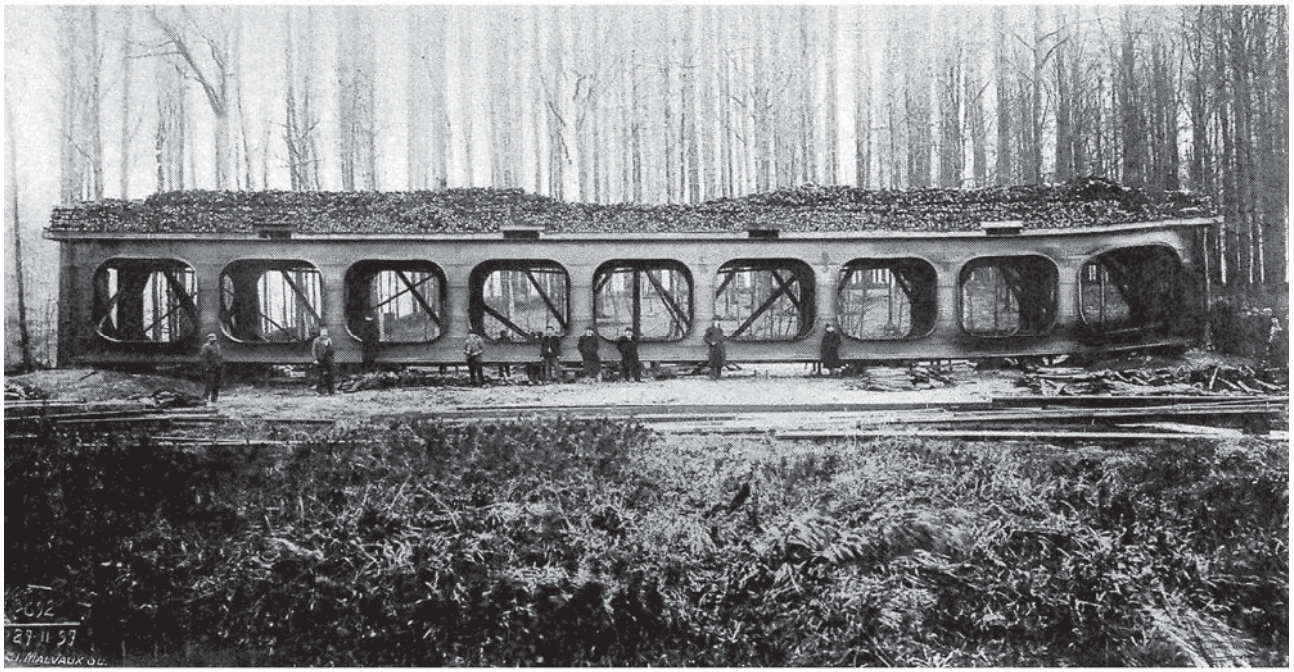


Figure 5: Experimental determination of strength of a Vierendeel bridge; (Lambin and Christophe 1898)

> Et maintenant le treillis : grande sujétion artistique du fer, car le treillis avec ses formes raides, droites, sans variétés, sans élasticité est un dispositif constructif qui n'est rien moins qu'esthétique ; mais heureusement, du treillis nous sommes délivrés ; voici un pont dont les fermes en fer sont réalisées sans intervention d'aucune diagonale, d'aucun treillis, et cette réalisation est obtenue en faisant une économie de matière et sans sacrifier de la solidité. (Vierendeel 1897, p. 14)

Colourful architecture

Structural aesthetics is derived from rivets, proportion, tie rods, columns and covering strips whereas auxiliary aesthetics can be created through adding ceramics, other metals and decorative painting. To the latter Vierendeel attributed a great part of this chapter.
In the nineteenth century architects such as Jacques Ignace Hittorff (1792-1869) noticed traces of paint on Hellenic architecture. The idea that classical architecture was polychrome slowly got accepted. Since Vierendeel was a great admirer of Greek architecture it should be no surprise that he wanted to transpose this classical ornamentation on a basically sober formal system to iron structures. Hittorff had already painted his cast iron structures and Vierendeel appreciated the application of it by decorative artist Owen Jones (1809-1874) on the Crystal Palace (Vierendeel 1902, p. 829). Colour was to hold up the structure as being the supportive element of architecture.

> Le fer, métal fort, exige des couleurs fortes. […] Sur les colonnes, sur les arcs, sur toutes les pièces qui portent et résistent il faut des couleurs franches, énergiques. […] Il existe un certain langage constructif des couleurs : une colonne peinte en rouge franc paraîtra plus solide. […] Une colonne en fonte, une poutre en fer, peintes en blanc n'ont absolument aucun sens. (Vierendeel 1902, p. 831)

Vierendeel took - once again - scientific developments into consideration when writing his theory on the use of colours.

> Deux teintes sont dites complémentaires lorsque par leur mélange elles produisent du blanc ou tout au moins du gris neutre. Nous avons vu ci-dessus que sous ce rapport il y a une notable différence entre les poudres colorées et les rayons colorés. Deux rayons l'un jaune l'autre bleu sont complémentaires, les pigments de ces couleurs ne le sont pas. La connaissance des couleurs optiquement complémentaires a une grande importance pour l'artiste car ce sont celles qui mises en présence s'exaltent le plus l'une l'autre. (Vierendeel 1902, pp. 836-837)

CONCLUSIONS

Canonical literature on the use of iron in architecture states that during the nineteenth century both architects and engineers were unaccustomed to capture the characteristic trait of iron. Opponents reproached its lack of mass and attributed it only a secondary role as a sculptural element or as an armature for stone and concrete constructions, whereas engineers were as a rule supporters.
For Vierendeel one has to nuance this opinion. Even the most impressive structures weren't able to evade his all-seeing eye as we mentioned for e.g. the Galerie des Machines. Vierendeel had been impressed by mass-like structures such as the Greek and Gothic architecture, and tried to attribute a same kind of weight to iron structures.
We can presume that Vierendeel came too late with his plea. In the beginning of the twentieth century the architectural debate had changed, not completely leaving out aesthetic discourses (cf Adolf Loos or Louis Sullivan), but their general arguments had shifted. When it comes to Vierendeel's aesthetic convictions we can say that he nestled himself in the safe arguments that had dominated style discussions in the nineteenth century both in writings and in buildings. His universal personality is thus relative. We could furthermore wonder why Vierendeel never gave any positive or negative comments on the Belgian neo-Gothic movement or the art nouveau. They could have been very grateful examples for his plea since they were less marked as industrial applications of iron.

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