

# Victor Horta's iron architecture: a structural analysis

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**Abstract.** The internationally acknowledged Art Nouveau architect Victor Horta built remarkable artifacts of public iron architecture in Brussels. His projects display an innovative philosophy based on apparent iron frameworks used in a very efficient manner. As a supplement to the ample historical and architectural studies on Belgium's most famous Art Nouveau architect, this paper puts Horta's innovative structural practice of iron into the picture. To reach this goal, a structural analysis of four of Horta's most interesting projects is carried out, going into the following topics: conceptual philosophy (structural typology), building techniques (shapes, connection details) and the coherence of the structural logic (structural usefulness).

**Keywords:** structural analysis, Victor Horta, iron constructions, innovative iron practice, structural logic.

## Introduction

The Belgian architect Victor Horta (1861-1947) was the greatest personality of the Art Nouveau architectural trend in Europe and was also one of the founders of Modern architecture. This analysis aims to extend the existing knowledge with a study of the structural aspects of Victor Horta's innovative and exemplary iron practice. Indeed, the architectural and ornamental topics of Horta's oeuvre have already been investigated in a detailed manner in the Belgian and international literature, (Frampton 1980, Loze 1991, Vandenbreeden and Dierkens-Aubry 2001, Aubry 2005, Delhay and Loyer 1988, Pieters 2005).

Inspired by the theoretical fundamentals of Viollet-le-Duc's works, Horta has put Art Nouveau concepts into practice from 1893 onwards. This led to the construction of remarkable iron structures, mostly located in Brussels (Belgium). In addition to the innovative conceptual spirit, the great merit of the architect was the introduction of the material 'iron' – which was at the time only accepted for industrial use – into the design of buildings. Although he has employed different materials (e.g. stonework, brickwork, wood,...), our investigations will exclusively focus on the use of iron. We aim to carry out a multidisciplinary structural analysis that will take architectural, historical, structural and esthetical parameters into consideration. To reach this goal, after a concise contextual analysis, the present research will emphasize the innovative use of iron, the new material that Victor Horta employs in a relevant manner. Then, based on this background information, we will implement the structural analysis on four famous buildings which belong to his oeuvre in order to understand the evolution of his design choices. This approach will allow a more suitable and relevant restoration of Horta's iron structures. (Basyn et al. 2003, Vandenbreeden and Dierkens-Aubry 2001)

## Historical and Structural Context

**Victor Horta, Art Nouveau and Important Personalities.** With his dynamic vision of life, Victor Horta developed new spatial and structural concepts that influenced fundamentally the architecture of the beginning of the twentieth century. Considering the social and cultural mutations and evolutions, the architect became aware of the need for new architectural programmes that had to meet the expectations of this period. He revolutionizes the typical traditional plan of the private house from Brussels (three adjoining rooms) by means of an organic ornamental architecture that privileges light and space. For this, Horta's inspiration was drawn from the theories of *Eugène Viollet-le-Duc*, a person whose projects are based on an important notion of rationality. According to his theories, it was necessary to step back from the traditional architectural rules and to privilege a consistency and a strong coherence between the plan, the façades and the purpose (functionality) of the building. Thus *the architecture of a building had to correspond with its structure and the use of a new material had*

to be reflected by the usage of new forms (design choices). In analogy, the Art Nouveau movement considered that each material type should be represented by its own formal expression according to its properties. For example, architect Alphonse Balat put these principles into practice for the complex of the Royal glasshouse of Laeken (Brussels) by combining stone and cast iron, each material using a different formal language. Thenceforward, the influence of Viollet-le-Duc on iron practice in visible structures of a large number of Belgian architects was consequently considerable.

As a student of Alphonse Balat, Victor Horta was especially influenced by these Art Nouveau theoretical notions. In addition, he strove to separate his architecture from the industrial sector in order to assert an own and new identity. This idea excels in the typology of his terraced houses where art and industry are at the root of the global design. As a consequence, Horta resorted to the new material iron (cast- and wrought iron) for which he developed innovative designs. (Archives d'architecture moderne 1986, Vandenbreenen and Dierkens-Aubry 2001)

**Structural and Technical Context.** Due to the use of iron, a material which benefits from efficient mechanical properties, Art Nouveau had also generated a constructional and structural renewal. To understand the reasons why Horta exploited these properties, it is necessary to situate this event into the technical context of that time: the theoretical knowledge, the manufacturing methods, the connection details and also the available sections.

During the nineteenth century, most of the iron constructions were quite humble structures or were even completely hidden. This phenomenon has to be connected with the use of this new material due to the technical and theoretical progress. Actually, the use of iron in the building sector is related to the development of the strength of materials: from the second half of the nineteenth century, an important progress of the calculation methods had cause the design of new structures. As for the joints and the fasteners, they were determined and dimensioned thanks to specific calculations and formulas. Considering its high cost, the geometry of iron shapes was the result of a research about the form of the structural component which aims to use raw materials in a sparing manner. Theoretical developments as well as experimental testing have permit to provide insights in the understanding of the structural behaviour of iron (elastic strain, assessment of yield strength and ultimate strength). (Andrieux 1991)

**Material, Joining Techniques and Shape Types.** Due to its casting capacity, cast iron was abundantly used and this iron grade had led to the arrival of new shape types. However, during 1840-1850 Hodgkinson and W. Fairbairn proved that the compressive strength of cast iron was definitely lower than its tensile strength. Subsequently, cast iron beams with asymmetric cross-section were little by little replaced by wrought iron from 1860.

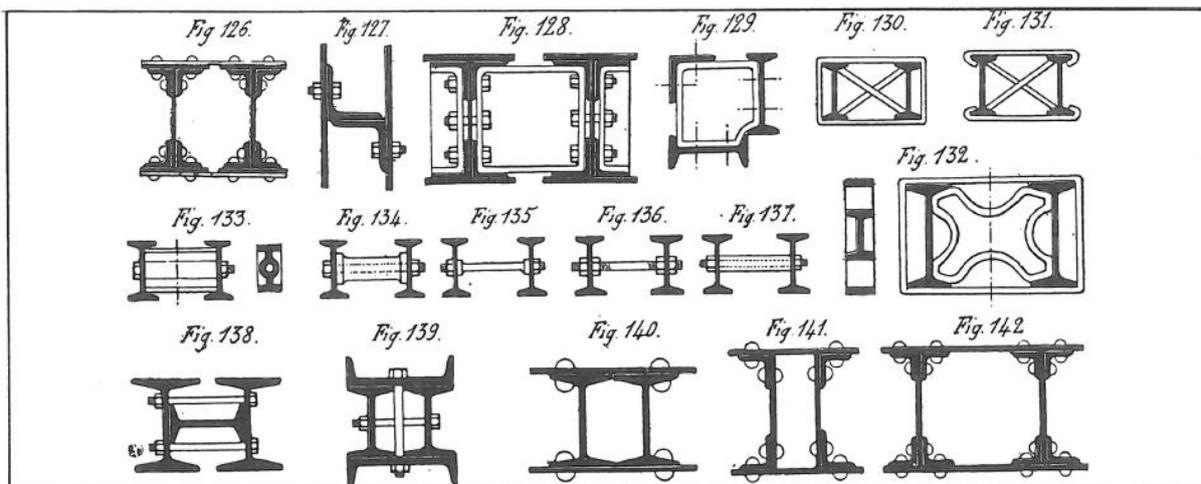


Figure 1: Example of several composed beam types made of shapes or twin beams (Lemoine 1986)

Although cast iron columns were still in use until 1900-1920, these were replaced by wrought iron most of the time as this material has identical properties in compression and in tension. In addition, an important number of new column and beam shape types were created, made of angles and plates assembled by rivets. These sections could easily be joined to the rest of the iron frame and were generally H-shapes, U-shapes and also square and rectangular box girders for high loaded structural

elements (Fig.1). Also, the material wrought iron had contributed to the development of lightweight floors composed of I-shape bearing arched masonry. (Lemoine 1986, Andrieux 1991)

## **Horta's Innovative Structural Practice**

**Presentation of This Innovativeness and Main Causes.** Before starting a detailed structural analysis concerning four Horta's buildings, we will first attempt to underline significant facts which reflect the innovative character of iron practice in his oeuvre. With the *Hôtel Tassel* built in 1893 (Brussels), Horta opted for the first time for visible iron structures with organic and natural forms. As a follower of the Art Nouveau trend, the architect became aware of the importance of clearly showing the mechanical properties of this new material. He designed visible structures whose forms ensue from the folding of sections in such a way that the final global design shows a *natural look* borrowed from nature. The architect actually considered the structure as a "living thing": a strong interaction is developed between the different structural components. This fact is showed by a big dynamic up to the connections between iron beams and bearing walls, wrought iron columns and masonry balcony, .... Being conscious of the progress related to the strength of materials, Horta exploited henceforth this material as well as possible in other words till its ultimate carrying capacity. This can be illustrated with the following quotation:

*"Je vous dis seulement que les matériaux sont restés identiques, vous le savez comme moi. Toutefois, alors qu'ils étaient utilisés de manière empirique dans le passé, une manière qui ne permettait pas de les faire travailler jusqu'à la limite de leur sécurité à cause de la peur de l'imprévisible, notre époque peut en revanche, grâce à la combinaison des résultats d'expériences et des formules mathématiques qui en découlent, permettre des constructions inconnues et audacieuses (...)"* (Pierron 1920, p. 2)

Thus, Horta used very reduced and slender cross-section for the different structural components of the structure. In the same spirit, the architect exploited the flexural stiffness of wrought iron to free space on the floor by enlarging the span length. Also, like a symbolic expression, the design of the structure mirrors the internal stress that occurs in the components; for example, the form of a beam shows the deflection due to the bending moment at midspan. The innovativeness lies in the desire of showing these structures as well as trying to use the carrying capacity of the material in an optimal way. (Vandenbreenen and Dierkens-Aubry 2001)

Also, we have to identify the reasons why Horta had used this new material and what was the function of the structural components within the building. Once again, the theories of Viollet-le-Duc combined with Art Nouveau fundamentals led Horta to transpose iron borrowed from the industrial sector to a smaller scale such as private mansions and department stores. This way, he wanted to conceive a light architecture where the fundamental research is related to one same issue: *providing daylighting*. As a result, the architect used this material to enlarge bay windows, build wide glass roofs and also free space at the floor. Thus the architectural renewal (rationalism, Art Nouveau) is at the origin of Victor Horta's innovative iron practice: the structural member is *at the disposal* of architecture, the functionality of the building and its occupants.

**Structural Logic: Ornamental or Structural Function?** Through the global oeuvre of Horta, we can regroup iron components within *three main categories*. First, the elements of the principal bearing structure of the building (beams, I-shape in masonry arched floors, columns): these totally unornamented components are sober and generally partially or not apparent. Secondly, we encounter structural components that locally bear secondary structures or architectural details (window opening, bow window, balcony, glass roof, roof dormer, winter garden,...): these ones are exclusively apparent and their design is quite sophisticated and elaborate (decoration, nature and studied forms). This second category in which the structural and the decorative function blend well together highlights however the existence of an inefficient structural logic in some configurations, for example: the iron shape does not completely assume its role of bearing loads. We can observe that esthetical considerations linked to design choices – the will to carry out a design where all materials become united and merged within the same dynamic, and whose shapes occur in nature – are of prime importance and damage the structural usefulness. Finally, the third category represents non structural shapes used for decorations, railings and technical equipments (lighting, radiator).

The *time notion* also has to be taken into account within the framework of the analysis of his structural innovativeness. Actually, as the structures are built and over time, we can notice that the two first categories tend to merge into a new one: the structural design is more relevant thanks to a better

structural logic. As a result, this evolution emphasizes a lessening about the esthetical research (architectural concepts) in order to promote an improved structural use of iron components.

### **Buildings' Analysis**

The multidisciplinary structural analysis concerns four emblematic buildings of Victor Horta for which the structure represents a relevant interest. These buildings - all located in Brussels - are the following ones: *Hôtel Van Eetvelde* (1895, private mansion), *Hôtel Solvay* (1895, private mansion), *Maison du Peuple* (1896-1899, public building) and *A l'innovation* (1901-1903, department store). (Delhaye and Dierkens-Aubry 1987, Aubry 2005)

**External Use – The Main Frontage.** For all of these buildings, a common feature is the will of enlarging the windows opening. To reach this goal, Horta replaces masonry lintels with iron shapes that are supported by small cast or wrought columns at midspan. This structural choice has led to the use of *the bow window*, a frequently employed typology in his oeuvre.

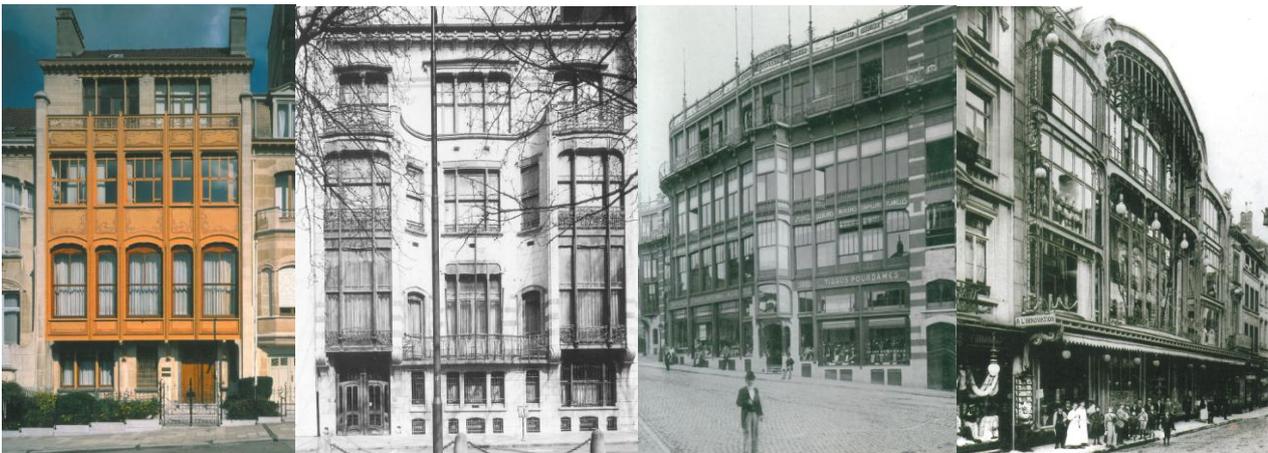


Figure 2: Main frontage of the *Hôtel Van Eetvelde* (Aubry 2007), the *Hôtel Solvay* (Loze 1991), the *Maison du Peuple* (Aubry 2007) and the department store “*A l'innovation*” (Aubry 2007)

Yet contemporary, the *Hôtel Van Eetvelde* and the *Hôtel Solvay* (Fig. 2) show a significant difference. Concerning the first one, Horta uses a more radical choice by enlarging the bow window over all the width of the façade. The iron structure asserts oneself regarding the employment of masonry which becomes more decorative. With the *Maison du Peuple* (Fig. 2), the structural role of iron becomes more important: the bearing structure is completely made of iron and it represents a coherent tracery of beams and columns in the form of shapes assembled by rivets and bolts. Masonry loses its structural function to amount to nogging (studwork, filing elements) - such as glass – between the mesh formed by the structure. This important growth of iron use at the façade is also clearly underlined with the *A l'innovation* department store (Fig. 2) where the windows area is maximized. Thus this evolution indicates Horta's wish of exploiting the efficient mechanical properties of iron - in comparison with stone/masonry – in order to be able to increase the glazed area and to limit at the same time the important size of masonry bearing walls.

**Internal Use – Principal and Secondary Structures.** Horta's oeuvre underlines the presence of composite structures – masonry/iron – where the bearing function of iron becomes more and more important as the structures are built. The principal structure of these constructions includes wrought iron beams that are often double or triple beams side by side and supported by bearing masonry walls. Over time, the architect gradually replaces these bearing walls by one column or twin columns made of cast or wrought iron. The structural difference between the *Hôtel Van Eetvelde* and the *Hôtel Solvay* (Fig. 3) does not concern the principal structure but the secondary iron frameworks such as the stairwell, the glass roof and the roof light.

Concerning the first building, these frameworks completely fulfill their structural function and benefit from a sophisticated form borrowed from nature at the same time. On the other hand, with the *Hôtel Solvay*, esthetical considerations encourage Horta to reduce the structural logic of these secondary structures. Indeed, their structural contribution is strongly limited given the fact that they are hanged to an other bearing structure which is not apparent.

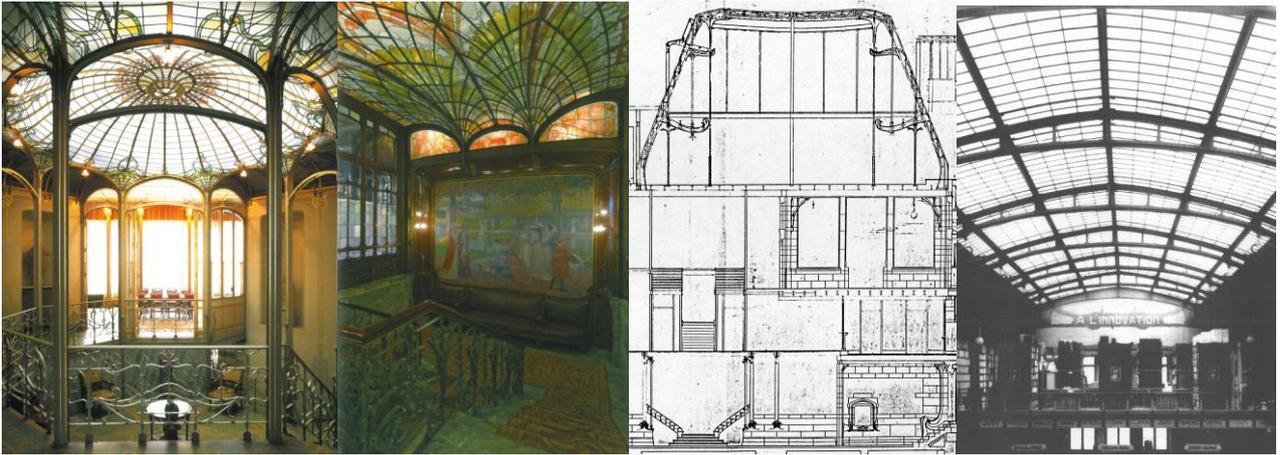


Figure 3: *Hôtel Van Eetvelde - Winter garden (Loze 1991), Hôtel Solvay – roof dormer (Aubry 2007), Maison du Peuple – transverse section (Horta Museum 2009), department store “A l’innovation” (Horta Museum 2009)*

In his structural design evolution, we can observe that this ambiguity is starting to go and this fact is confirmed by the structure of the *Maison du Peuple* (Fig. 3). For this building, the architect uses apparent portal frames and a network of triangularly braced beams which combine the following qualities: a coherent plan of the structure, an apparent structure, a real structural function and a researched design. With the fourth construction, the *A l’innovation* department store (Fig. 3), the architect improves his structural concept where the esthetical parameter is no more “decorative” (shapes with a form that occurs in nature) but concerns the structural principle taken as a whole (beauty provided by the employed structural logic).

**Constructional Details.** We will analyse in a more extensive manner the connection details and the composition of the shapes used in the *Hôtel Solvay* and the *Maison du Peuple* (Fig. 4). Victor Horta adopted a double policy: on the one hand he employed shape types and connection methods in keeping with the contemporary technique, one the other hand he innovated in the field of the design of non straight shapes characterized by a variable inertia.

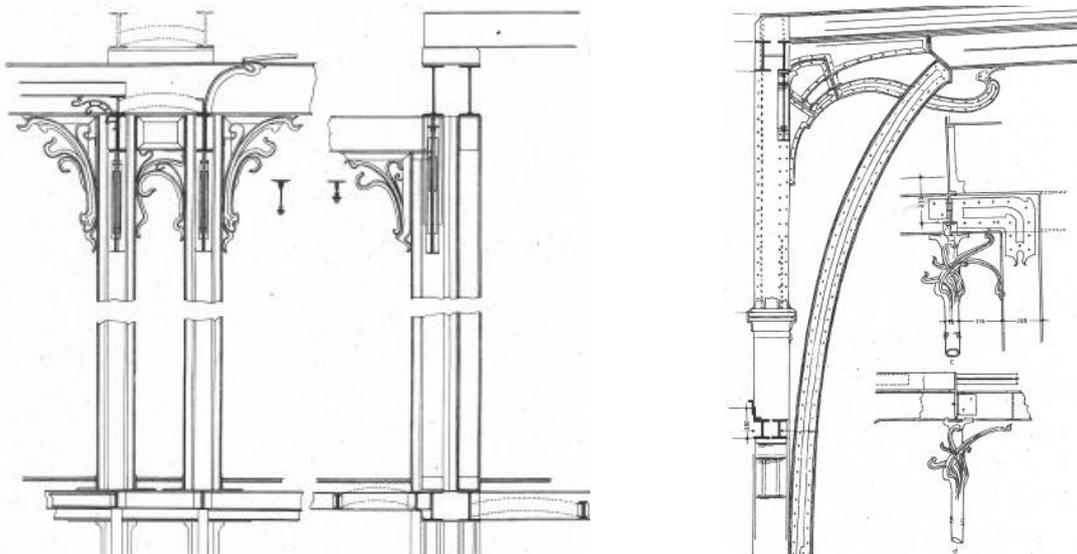


Figure 4: *Constructional details of the Hôtel Solvay (Horta Museum 2009) and the Maison du Peuple (Horta Museum 2009)*

The beams and the columns of the principal structure are shapes composed by wrought iron angles and/or plates assembled by rivets (however some columns are made of cast iron). The cross-section of these beams reveals a form – highlight of the constructional practices of the time - that can be compared to a juxtaposition of two or three I-shapes. Nevertheless, the structural innovation is more marked for the capital of the columns (Fig. 4 – *Hôtel Solvay*) and for the bracket (Fig. 4 – *Maison du*

*Peuple*). Concerning the bracket of the *Maison du Peuple* (Fig. 4), although some shapes only bear a small part of the imposed loads, the bending moment that occurs on the complete restraint connection is taken into account by Horta who spreads out in the space these arched shapes in order to increase the moment of inertia. Once again, this innovative practice presents some less relevant structural choices due to the influence of esthetical considerations, for example (Fig. 4 – *Maison du Peuple*, right-hand side): the structural column is accompanied by an additional column that does not play an important part in bearing the loads.

## Conclusion

This multidisciplinary structural analysis presents the main characteristics of Victor Horta's structural innovativeness. Guided by the Art Nouveau and the theoretical knowledge of the strength of materials, the architect exploits the efficient mechanical properties of these iron structures which he considers as an alternative to traditional masonry bearing structures. Though his first constructions show a reduced structural logic due to esthetical considerations, Horta succeeds in developing his design choices by improving the relevance of these structural concepts. In his oeuvre, the architect learns to take advantage of the ambiguity between architectural, esthetical and structural issues in order to design structures where the form of the material is governed by structural needs. We can conclude that this significant structural innovativeness of iron practice clearly proves the importance of the architectural heritage conceived by Victor Horta, the greatest international figure of the Art Nouveau architectural trend.

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