ABSTRACT: This paper contributes to an understanding of the early application and technology of the Hennebique system of reinforced concrete construction in Belgium. By focusing on one specific building typology (urban warehouses) built in a short timeframe (1892-1914) in Belgium, we show the similarities among these early reinforced concrete structures, but also the variety of technical details applied within the Hennebique system. Indeed, urban warehouses, as functional buildings, were structures in which new technologies and materials were quickly adopted. The search for increased spans, higher load-bearing capacity and greater fire safety intertwined with the advantages of reinforced concrete in the Hennebique system. The files on urban warehouses in the archive Fonds Bétons armés Hennebique (BAH) are used as primary sources, complemented by an analysis of planning applications and onsite visits, to gain insight into the construction process and the actors involved.

KEYWORDS: Early 20th century, Belgium, Urban Warehouses, Early Reinforced Concrete, Hennebique
The files examined cover both preliminary designs and realized warehouses built of reinforced concrete. They typically include a letter from the Belgian licensee or from the Brussels office sketching the building to be calculated and the loads to be applied, a calculation note and a preliminary design drafted by the office mentioning dimensions of slabs, beams and columns. In the case of structures actually built, the files also include detailed drawings with the rebars. In some cases, the drawings of the architect or the building specifications are attached, which indicates whether the building was already designed in reinforced concrete or if a preliminary design was requested by the licensee to serve as a counterproposal. Although the Belgian licensees were spread proportionally over the country, the files on urban warehouses were mainly for buildings in the cities of Brussels, Antwerp and Ghent. The information from these files is complemented by an analysis of planning applications in the city archives of Antwerp (CAA), Ghent (CAG) and Brussels (SAB) and by onsite analyses of the still existing urban warehouses.

This paper will present the variety of structural solutions and technical details for reinforced concrete warehouses designed according to Hennebique’s patents from 1892 to 1914. As this paper takes the BAH files as a starting point, we adopt the dating system applied in the Hennebique company’s central office when referring to a warehouse. Several designs of warehouses will be discussed in greater detail, namely the earliest design for a reinforced concrete warehouse in Antwerp in 1894; one for rebuilding of a private warehouse in 1903; and six for public and port warehouses in Antwerp, Brussels and Ghent (1904-12). This selection allows us to highlight typological and structural characteristics and peculiarities, as well as a chronological evolution. For each type, the paper discusses the contribution of the Hennebique company’s office in Brussels and/or Paris, the contributions of other actors involved (mainly the licensees, the architect and the engineer) and the construction details or the material specifications. As the research was not limited to these cases, the discussion incorporates findings from a comparative analysis of over 50 cases: this broader framework provides insights into the relationship between the Brussels and Paris offices, the input of the different actors involved, types of structures that were realized, the dissemination of knowledge, speed of construction and the motives or incentives to build in reinforced concrete.

2 EARLY WAREHOUSES. A DESIGN FOR A WAREHOUSE IN ANTWERP IN 1894

The earliest file in the BAH archive for a multi-story urban warehouse in Belgium dates from 1894. It concerns a warehouse designed by architectural engineer Henri Hertogs (1861-1930). Remarkably, Hertogs corresponded directly with the Hennebique company’s office, without a licensee acting as intermediary. In fact, no licensee was ever appointed, as the design of this coffee warehouse was not executed. Nevertheless, the file yields valuable information on the organization of the first Hennebique company’s office in Brussels, the role of the architect and construction details in this experimental period, when the Hennebique system was still evolving.

2.1 Starting up the Brussels office

The file for the design of the coffee warehouse was given number 443. This number is mentioned on the grey cover of the file, next to a pre-printed label listing the name of the project (‘Magasin à cafés’), the client (‘Ceuclidean à Anvers’), the architect (‘Hertogs à Anvers’) and the licensee (left blank). The well-organized and coherent classification system developed in the Bureau Technique de Bruxelles catches the eye. Hennebique opened this Brussels office in 1892 to exploit his patent and to design and calculate constructions in reinforced concrete (Hellebois 2013). In 1894 a second office was opened in Paris, which became the head office from 1897 onwards.

2.2 Designing in reinforced concrete

The earliest documents in the file are a plan and section of the warehouse, drawn by Hertogs on November 30, 1894. The 600 m² warehouse has an 18 m-wide facade and three floors, and is covered by a hipped roof. The imposed load is 1500 kg/m² for the first and second floors, and 900 kg/m² for the third floor. Architectural engineer Hertogs conceived the floor slabs, the main beams and columns in reinforced concrete, which is quite surprising for such an early design. The roof frame was designed as a typical metal Polonceau truss. The Bureau Technique de Bruxelles drew up a detailed structure in reinforced concrete. The engineer of the Bureau Technique de Bruxelles copied Hertogs’s general plan and positioned the columns on a grid of about 3.60 m by 3.70 m. The span of the reinforced concrete slab was reduced to 1.80 m by adding secondary beams. Five days later, the engineer drew a proposal to construct the roof in reinforced concrete. To calculate the total price of the project, the cost of the steel (per kg) and concrete (in m³) were added, plus a cost for the formwork. The price of a floor then came to about 14 to 15 francs/m².

The planning application, which was submitted by Hertogs in January 1895, does not reveal the materials used (CAA 1895#29), but an onsite investigation of the coffee warehouse, located at Hessenplein in Antwerp, shows a construction with cast iron columns supporting metal beams. The floors, which typically were constructed in brick jack vaults, in this warehouse were constructed of (unreinforced) concrete
vaults supported by metal beams. Hennebique’s proposal apparently was not able to convince all parties to accept an all-reinforced concrete frame, but several of Hertogs subsequent reinforced concrete projects, calculated in the Hennebique company’s office, would be realized in the coming years.

2.3 Construction details, 1892 and 1896 patent

In 1892 François Hennebique patented a system to construct a slab in reinforced concrete (no. 100461). However, the construction details of the 1894 preliminary design of the coffee warehouse do not reflect this 1892 patent, but are identical to the system patented by Hennebique in 1896 (no. 123637). This is illustrated by the details shown in figure 2: the main beam of the 1894 coffee warehouse design is reinforced by two round straight rebars and typical U-shaped stirrups. Near the columns, the rebars are not bent upwards to follow the bending moment in the beam, which consequently creates an insecure beam-column connection. This flaw was addressed in the 1897 patent (no. 132618). The limited number of rebars also implies quite large diameters. According to Paul Christophe (1870-1975), an engineer working at the Service des essais de ponts and author of the reference work Le béton armé et ses applications, Hennebique used rebars with diameters of up to 50 mm (Christophe 1902, 107). The early files in the BAH archive indeed show large diameters. In the case of the coffee warehouse, the main beam, spanning 3.60 m, has two rebars of 38 mm and 31 mm to resist imposed loads of 1500 kg/m² and 900 kg/m², respectively. In contrast to the still-evolving design of the beams, the design of the columns was already well developed in 1894. From the ground level to the second floor, the square section of the columns decreases from 30 by 30 cm, to 25 by 25 cm and then to 20 by 20 cm. Four round bars, positioned in the four corners, are interconnected via plates every 40 to 50 cm. Typical for this early construction are the chamfered corners of the connection plate. In the following years the shape of these plates will be simplified to a rectangular shape. The concrete slab, 8 to 10 cm thick, is reinforced in only one direction: 15 mm diameter bars are applied every 25 cm for the 1.80 m span. (Fig. 2)

2.4 Dissemination of reinforced concrete

Given the experimental character of reinforced concrete at that time, it is intriguing to discover that Hertogs designed the warehouse in reinforced concrete before submitting a plan to the Hennebique company’s office. By whom or by what was Hertogs’s interest in concrete triggered? He could not have been inspired by Le béton armé, as the first issue only appeared five years later, in 1899. We do know François Hennebique worked hard to persuade various building actors to adopt reinforced concrete at this early stage. For instance, he invited the Société Belge des Ingénieurs et des Industriels (SBII) to witness onsite loading tests at his atelier in Sint-Jans Molenbeek and organized a visit to the nearby warehouse of the Confiserie Hallkett in 1895 (Hellebois 2013, 49). In addition to his main argument that reinforced concrete was fire resistant, another argument important to owners of warehouses and industrial buildings was found in the BAH files of the Confiserie Hallkett: “the monolithic concrete slab has a perfectly horizontal floor surface and a strength comparable to a floor in cement-tiles, is watertight and without cracks” (BAH 076 IFA 1002/5).

From 1899 onwards, the dissemination activities would scale up with the publishing of the journal Le béton armé and the organization of the yearly congress of the Concessionnaires et Agents du système Hennebique. Hennebique also invited the administrators of Belgian public works to attend this yearly congress. Among others, engineer Paul Christophe joined the third and fourth congress in 1899 and 1900 (Hellebois 2013, 167) and engineer Jules Zone (Société du Canal et des Installations Maritimes) was present at the 1900 congress (Van de Voorde 2011, 49).

3 PRIVATE WAREHOUSES. THE BRASSINE-DE BOECK WAREHOUSE IN BRUSSELS (1903)

In the period 1895-1902, Belgians ordered many preliminary designs for reinforced concrete structures and a substantial part were realized (mansions, hotels, schools, bridges and factories) but none of them con-
cerned urban warehouses. The second case study is the Brassine-de Boeck warehouse in Brussels, designed and built in 1903 (situated on rue de la Cuiller 3, now demolished).

3.1 Brussels versus Paris offices

In 1897 the Paris office became the central office ‘Bureau technique central à Paris’. From then onwards, project calculation notes were either made in the Brussels office and sent to Paris for verification, or made in the Paris office if the number of demands exceeded the capacity of the Brussels office. Correspondence contained two numbers, referring to the numbering systems of both offices. For example, the 1903 request to reconstruct a warehouse for Brassine-de Boeck in Brussels is numbered 18191/1471. These two numbers reflect the huge difference in volume: while the Brussels office was working out its 1471st order, the Paris office had already handled 10 times as many projects (18191).

When compared to the earliest documents, drafted in the 1890s, the documents that were drafted at the beginning of the twentieth century are similar yet more compact. The preliminary design for the Brassine-de Boeck warehouse gathers all information on one document: dimensions of the structural grid, dimensions of beams and columns, the thickness of the slabs and the imposed loads. The execution file contains one large drawing for each floor, with a scale of 1/50; mentions the dimensions of the primary and secondary beams and the spans; and indicates the amount, diameter and placement of the rebars in the slabs. (Fig. 3) The primary and secondary beams are numbered, corresponding with the table next to it, that shows the amount, dimensions and position of the rebars and stirrups. The drawing also contains a general section through the building, on a scale of 1/100, indicating the dimensions of the columns. For each type of column, corresponding with the capital letters on the general floor plan, a section is drawn on a scale of 1/10, indicating the position of the connecting plates and the dimensions of the rebars. (Fig. 3)

3.2 Hennebique licensees

The available communication between the Brussels and Paris offices in the post-1897 period enriches our knowledge as it provides more information on actors, in particular the licensees. In the period up to 1914, 45 licensees in Belgium are mentioned in the monthly lists of ‘travaux exécutés’ and ‘concessionnaires’ in the company journal Le béton armé. Of the 50 urban warehouses we studied, only a small number of the listed licensees is involved: licensees Bolsée & Hargot, Delvaux, Hargot & Somers, Hambresin, Louis De Waele, Mynck frères, Roy and Vigneron. Unlike in other countries, where often a licensee was
responsible for a limited geographic area, in Belgium Hennebique collaborated with many contractors (Van de Voorde 2011, 47). Hennebique not only allowed licensees to operate in more than one city and in the same cities as other licensees, but he also stimulated the competition between them. This is illustrated by the letters engineer Louis Deblon, Hennebique’s Brussels agent, sent to the Paris office. In 1908 Deblon requested that the preliminary design of a Brussels wine warehouse be sent to both licensees Delvaux and Hambresin in order to beat competitor Blaton (BAH 076 IFA 1291/15). Letters also provide information about Hennebique’s competitors. For instance, in 1905, Deblon explained that the low cost (9 francs/m²) for building the floors of a textile warehouse in Dison resulted from competition between licensee Ambroise Roy and other contractors, Blaton in Brussels and Ways & Freytag. Other letters illustrate the efforts undertaken by licensees to convince architects and clients to build in reinforced concrete. In the BAH we came across several files of licensee Louis De Waele requesting a counterproposal. For instance, in 1905 De Waele requested a preliminary design for the textile warehouses designed by architect Louis Bral, which consisted of brick arches supported by cast iron columns. However, the client or architect were not receptive to using concrete.

In the case of the Brassine-de Boeck warehouse, it was not difficult to convince the client to construct it in fire-resistant reinforced concrete, as the client had just lost his warehouse in a fire. Moreover, licensee Louis de Waele argued that the warehouse could be rebuilt faster using reinforced concrete (BAH 076 IFA 1032/29).

3.3 Construction details

The records of the 1903 design of the Brassine-de Boeck warehouse preserved in the BAH archive give an impression of the speed of execution. Louis De Waele sent an architectural drawing of the warehouse to the Brussels office, which the architect signed on January 20. The Brussels office drew up the structural plan, and engineer Mihrtadianz forwarded the documents to Paris the next day, on January 21. The central office in Paris delivered the execution plan of the foundations and the columns on January 24. Nevertheless, construction was proceeding quickly, and Mihrtadianz sent an urgent request to Paris on January 29 explaining that the formwork of the first floor was ready, and they awaited the rest of the execution plans. This letter must have crossed one sent by the Paris office, as the execution plan of the first floor is dated January 28. Other plans soon followed: the plan for the second floor is dated January 30, while the third floor and roof plans were drafted by February 3. In short, all execution plans were delivered in less than 14 days after the architectural design was sent.

The construction details of the building coincide closely with those of the 1897 patent. (Fig. 4) The beams contain at least two rebars, positioned one above the other. The lower rebar runs straight throughout the beam, the upper rebar is bent upwards near the column. The position of the rebars in the slab is more refined. Rebars are now positioned in two directions: the largest rebars span the shortest distance and consist of alternating straight and curved rebars. Smaller rebars are positioned in the perpendicular direction, to repartition the loads over the slab. (Fig. 3)

The construction of this floor slab is, however, rather atypical compared to those in other Belgian warehouses designed by Hennebique. First, the span of the slab (3.20 m) is quite large, which is confirmed by the guidelines given by Paul Christophe in his 1902 handbook: he recommended a maximum of 3.00 to 3.50 m (1902, 107). Moreover, as this structure had a high imposed load of 1000 kg/m², it was deemed necessary to create a slab reinforced in two directions and supported by four identical beams, resulting in a very uncommon squared structural grid of 3.20 by 3.20 m. The majority of the 50 warehouses in our study have floor slabs supported by secondary beams, which reduce the spans of the slabs to about 1.50 to 2.00 m. If the structural grid is oblong, a vaulted floor is used, which spans the shortest direction. This is well illustrated by the design proposals of 1905 for the warehouse for Moemmersheim in Antwerp. (Fig. 5) Engineer Somers from licensee Bolsée & Hargot sent a letter to the Paris office requesting designs for four alternative scenarios, for both flat and vaulted floors, supporting an imposed load of either 2000 or
When city architects and engineers were convinced of the advantages of reinforced concrete, they designed royal and port warehouses in this new material. Plans and building specifications were prepared before the construction of the warehouses was put out to tender. Hennebique then had to shift his focus from convincing actors to accept the new material, to designing structures in such a way his licensees could present the best offer within the strict conditions of a public tender. Previous research has revealed that Hennebique did not shy away from urging the city administration to include the Hennebique system in the building specifications (Wouters et al. 2016). By studying the designs of three port warehouses in Antwerp (1904), a Royal warehouse in Brussels (1904) and two port warehouses in Ghent (1911, 1912), available in the BAH archive, we can see how Hennebique tried to adapt the logic of his system to the existing designs for royal and port warehouses.

4.1 City and port engineers

Due to a great fire, the Antwerp Entrepot Royal was completely destroyed in 1901. In 1904, chief port engineer Frans Dewinter (1859-1922) and chief city engineer Gustave Royers (1848-1923) drew up plans and building specifications for its reconstruction. The first project (now demolished), two low-rise warehouses Magasins A & B of the Royal Entrepot, was detailed in its architecture, but quite vague about its structure in reinforced concrete, which had to carry 2000 kg/m². Based on this plan, the Paris office designed the reinforced concrete structure in April 1904. For the oblong structural grid of Magasin A (4.00 m by 7.14 m) the Paris office proposed a reinforced concrete vault spanning 4.00 m supported by a beam on both sides. The rectangular grid of Magasin B (6.00 m by 8.00 m) was designed as a 14 cm-thick slab supported by secondary beams every 2.00 m resting on primary beams, spanning 8.00 m. Those two proposals (vaulted floor, slab with secondary beams) were often applied by Hennebique and could be considered as ‘standard’ solutions to carry heavy loads.

In their next project for the reconstruction of warehouse Nord-Ancien and Nord-Nouveau of the Entrepot Royal, Dewinter and Royers included more details about the concrete floors (capacity 2000 kg/m²) of the five-storey warehouse. The oblong rectangular grid (4.20 m by 6.20 m) was already designed as a vaulted floor, with vaults spanning 4.20 m supported by a beam on both sides (BAH 076 IFA 1131/36). The structure of this warehouse, now demolished, is similar to the still existing structure of the Brussels Entrepot Royal, located at the avenue du Port, which was designed in 1904 for the Société du Canal et des Installations Maritime by chief engineer Jules Zone and licensee Louis De Waele, and completed in 1906. (Fig. 6, right)

Also, the third warehouse, the five-storey Godfried warehouse located at the Godefridus quay in Antwerp, again designed by Dewinter and Royers, was detailed in a way that favoured the Hennebique system, or at least was compatible with it. The engineers reduced the span of the floor slab by supporting it every 1.50 m with secondary beams, which were carried in turn by the main beams spanning 6.30 m. (Fig. 6, left) On September 1, the Paris office added dimensions to the slabs, beams and columns, taking into account an imposed load of 2000 kg/m² (BAH 076 IFA 1092/1). The Antwerp licensee Bolsée & Hargot was able to make the best offer, was awarded the job on September 8 and completed construction in 1905.

However, the designs put forward by the administrations did not always fit the logic of the Hennebique system. In Ghent, the existing metal-framed hangars next to the Voorhaven dock were enlarged by building four new hangars in two phases. In 1910, city engineer V. Compyn drafted building spec-
ifications for the first two hangars. In 1912 the buildings specifications for the next two were prepared by engineer A. Hauspye and chief city engineer V. Compyn. Although the imposed loads (1500 kg/m² on first floor and 800 kg/m² on second floor) and the available building sites are comparable, the structural solutions in the reinforced concrete designs are different.

The letters in the BAH files reveal the communication between the Brussels agent Deblon, the Ghent city engineer Compyn, the Ghent licensee Myncke and the Paris office. Deblon explained that the Paris office had to stick to the design of the Ghent engineer. Only the amount of steel bars could be adjusted, as this was not mentioned on the drawings. The Paris office wanted to reduce the thickness of the slab from 18 to 10 cm, reverse the direction of the span to make the primary beams run in the longest direction and reduce the dimension of secondary and primary beams (BAH 076 IFA 1506/4).

The 1912 design was even more distant from the standard Hennebique structure. The Ghent engineers proposed a flat slab in reinforced concrete, 25 cm thick, spanning 4.50 m supported by heavy primary beams (35 cm by 50 cm) with spans of 6.00 m. The Paris office prepared the preliminary design, accompanied by a counterproposal that followed the Hennebique logic: a slab of 12 cm, supported every 2.10 m by secondary beams (15 by 30 cm) resting on primary beams (20 by 35 cm) spanning 4.50 m. Deblon asked the Paris office to send these proposals to both licensees Hambresin and Vigneron (BAH 076 IFA 1574/3). The four Ghent hangars (now demolished) were constructed in reinforced concrete but it is unclear who built them.

4.2 Material specifications

The calculation notes found in the BAH archive do not give much information about the characteristics of the materials used, but the building specifications drafted by the port and city engineers do. The original building specifications are included in the BAH files of the design of the abovementioned warehouses: Cahier des charges no. 1008: Entrepot Royal - construction de deux magasins dans la cour sud in Antwerp (1904), Cahier des charges no. 1144: Entrepot Royal - reconstruction des pavillons ‘Nord-Ancien’ et ‘Nord-Nouveau’ in Antwerp (1905), Lastcohier 1250: Bouwen van twee loodsen in Ghent (1911) and Lastcohier 1352: Bouwen van twee loodsen in gewapend beton in Ghent (1912). They provided information on elements believed to influence the quality and strength of reinforced concrete: the quality of iron and mild steel, the performance of cement, the concrete mix and the aggregates.

The description of the quality of Portland cement is strict as are the performance requirements (sieving, setting time and strength development). It is quite remarkable that all building specifications add a paragraph on the storage of cement at the building site. Cement should be stored in a separate building that protects it from humidity. The building should have only one door and the entrance to the building must be controlled in several ways. For instance, the 1904 Antwerp building specifications mention that the door must have two locks, one belonging to the contractor, the other belonging to the controlling agency. The building specifications for the 1911 Ghent port warehouse mention the contractor had to hand in the key every day at the office of the controlling agency. And when a new amount of Portland cement was delivered, it had to be stored separately and tests had to be performed on the new amounts. These regulations illustrate the concern that contractors might use inadequate cheap cement.

In 1902 Paul Christophe described the quality of iron and steel that should be used in reinforced concrete: iron N°3 with a tensile strength of 32 to 36 kg/mm² and an elongation of 8 to 12 per cent. The 1904 building specifications for the warehouses mention the use of mild steel with a tensile strength of 42 to 50 kg/mm². Paul Christophe recommended the latter quality mainly for the construction of bridges (1902, 400). Thus, in warehouses, which have to resist high imposed loads, steel with superior qualities was recommended.

4.3 Calculation notes

As part of the public tenders for building the aforementioned royal and port warehouses in Antwerp, Brussels and Ghent, the building specifications stipulated that the offers had to be accompanied by an explanation of the calculation method.
The Paris office used a standard description adjusted to echo the technical requirements mentioned in the building specifications. Yet, not all engineers agreed with the method Hennebique applied. The letters at BAH reveal that engineer Jules Zone, who superintended the construction of the Brussels Royal Entrepot, was not satisfied with the calculation offered by Hennebique: in 1905 Zone requested the addition of a calculation note on the stirrups and larger reinforcement in some beams (BAH 067 IFA 1102/7).

5 CONCLUSIONS

The study of early urban warehouses in Belgium, designed by Hennebique or constructed by Hennebique licensees revealed that the technology evolved in the first years by improving the position, shape and number of rebars. The floor spans increased from 3.60 by 3.70 in 1894 to 6.00 by 8.00 m in 1912. However, the structural grid of a warehouse also depended on the geometry of the intended building site, the weight and characteristics of goods to be stored and whether the building was originally designed in reinforced concrete or only constructed this way because it proved less costly. Nevertheless, some general tendencies can be discovered in the more than 50 designs studied. To carry high loads (1000kg/m² to 4000 kg/m²) Hennebique had mainly two options: he could decrease the span of the floor slab by inserting secondary beams, or he could construct the floor with vaults. These standard solutions come even more to the fore when Hennebique had to adapt his designs for the projects of the Ghent port warehouses.

In addition to the information revealed by the technical details of the Hennebique system itself, the files of the Bureau Technique Central allowed us to discover more about the broader context. From the surviving letters sent to the office, we discovered, from time to time, information about financial aspects of Hennebique’s licensees and his competitors. The letters also reveal the arguments which were put forward for using reinforced concrete to construct urban warehouses. As well as its fire resistance, high load bearing capacity and fast construction, reinforced concrete made smooth, waterproof floors, a valuable feature for these warehouses.

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