Refurbishment of Industrial Buildings in Early Reinforced Concrete

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ABSTRACT: The presence of François Hennebique in Belgium until 1896 certainly urged the use and spread of reinforced concrete as a building system in Belgium. Although numerous buildings were erected, not much of them have survived the 21st century. The early witnesses are now protected as historical monument. However, their refurbishment is a long and difficult process. The paper explores in depth the architectural and technical design process of two renovated industrial buildings in Belgium: the *Vuurmolen* (1902) in Overijse constructed according to the M. Dumas patent, and the *Royal Entrepot* (1903-6) in Brussels, constructed according to the Hennebique patent. By going into the construction history, re-use, assessment, strengthening and thermal upgrading, it becomes clear that there are no standard procedures for the rehabilitation of these multiform early industrial concrete buildings.

EARLY REINFORCED CONCRETE

At the end of the 19th century, reinforced concrete was introduced as a construction material. The economics and the fire safety were leading motives for its use in all kinds of applications: from foundations and maritime constructions to houses and municipal halls. The presence of François Hennebique in Belgium until 1896 certainly influenced and urged the use of reinforced concrete. In this period Hennebique built among others the Villa Madoux in *Lombartzyde* where he first applied reinforced concrete slabs and in 1892 took his well known patent on his beam in reinforced concrete. From 1892 onwards, when he actively made propaganda by inviting engineers and architects to his Brussels lab, his network began to expand. This resulted in the construction of a sugar refinery in 1893 in *Lille* (France) and the opening of an engineering office in Paris, one year later (Baes, 1930). In 1896 Hennebique definitely moved his central office to Paris, but the cross links between Belgium and France would never been cut. Engineers, architects and industrialists from both countries were exchanging projects and expertise (Baes, 1930).

In 1899 the Belgian engineer Paul Christophe brings together the existing knowledge on the calculation of reinforced concrete in his writings '*Le béton armé et ses applications*'. The extended reprint of 1902 was appreciated by engineers worldwide not only for the clear exposure of the calculation method but also for the classification of the amalgam of existing patents and systems.

Many of the early industrial buildings in reinforced concrete have disappeared by now. The ones that survived are listed as historical monument. Nevertheless, the conservation of these early concrete industrial buildings is a greater challenge than one might expect on first sight.

Due to their industrial activity, they have always had an important influence on their environment. On the one hand they caused intensive traffic, noise or an unpleasant smell, on the other hand they promoted employment and the development of the neighbourhood. When abandoned they were a source of criminality. So these building sites are interwoven with the history and the life of the city and the citizens. The problem of rehabilitation is more complicated than only finding a technical solution.

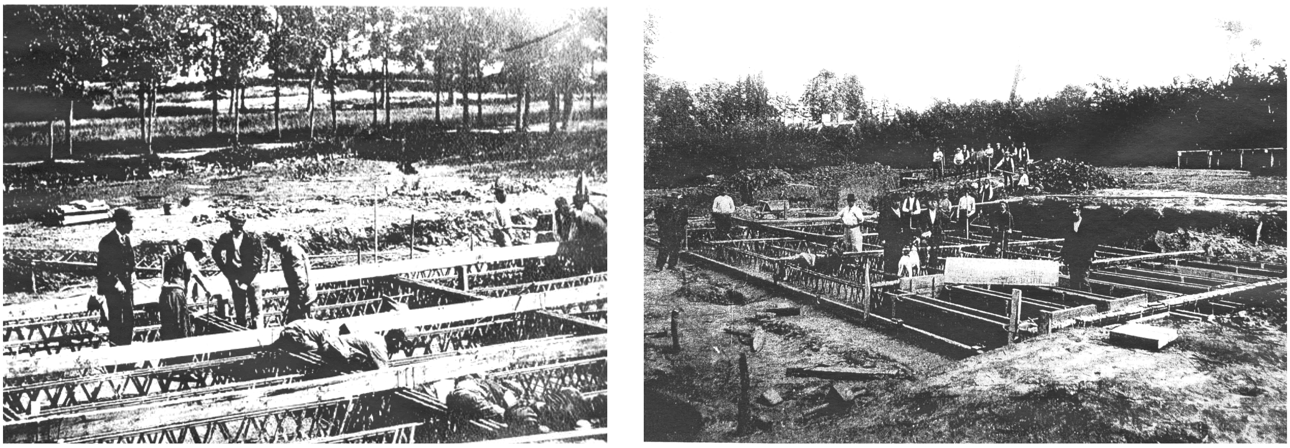

Figure 1: Vuurmolen. Foundations in reinforced concrete of the flour-mill at Overijse in summer 1902
(Photo Archive R. De Coster)

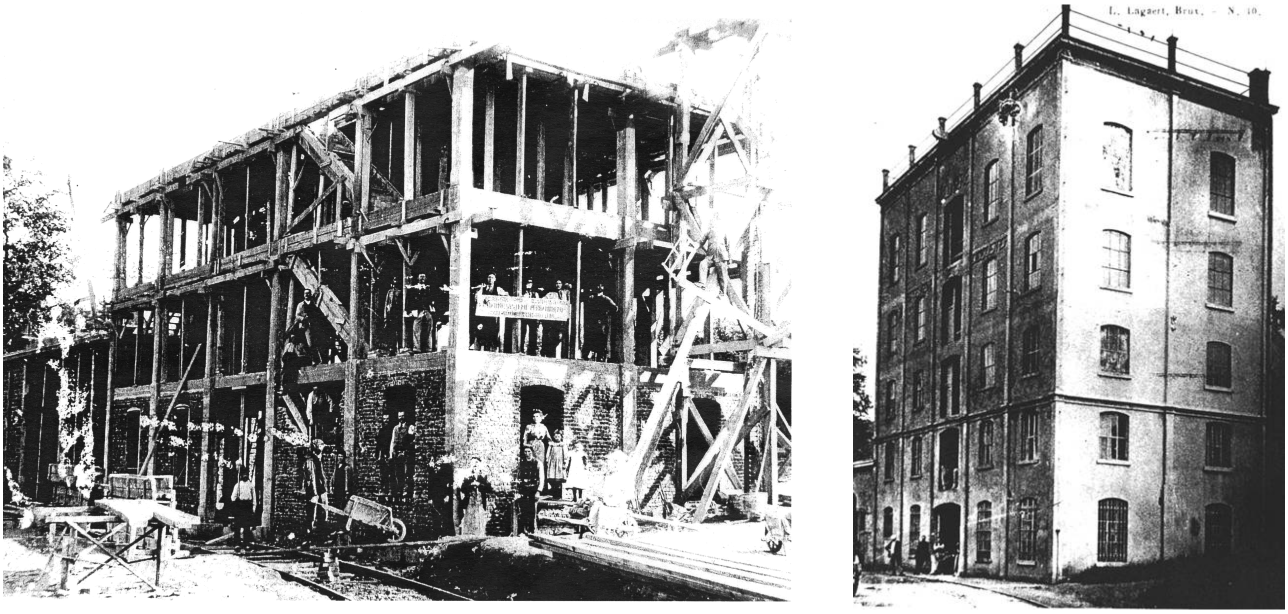

Figure 2: Vuurmolen. Reinforced concrete frame with brick infill (left) and completed (right)
(Photo archive R. De Coster)

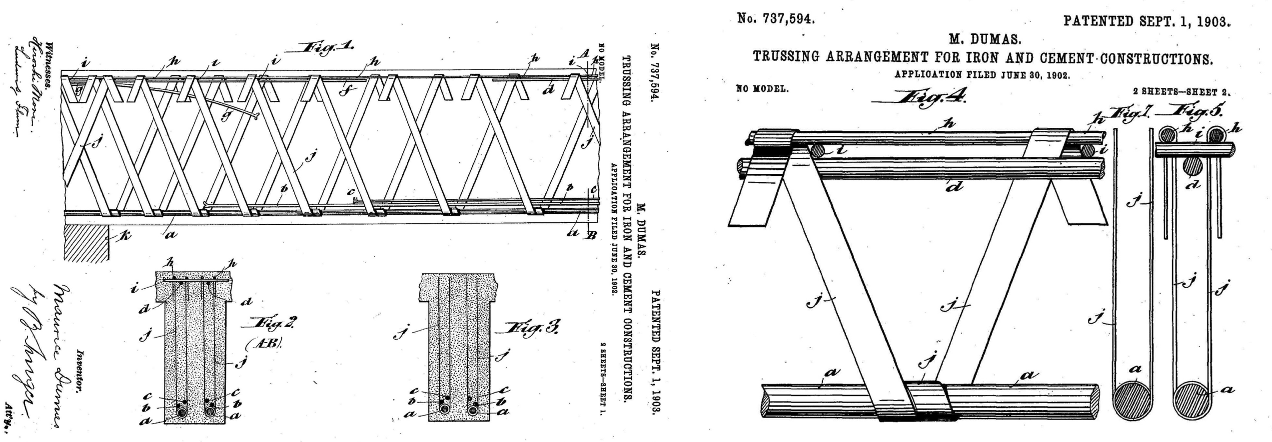

Figure 3: Patent ‘trussing arrangement for iron and cement constructions’ from Maurice Dumas (Patent 1903)

Due to the expressivity and the many appearances of reinforced concrete, the material is associated with aesthetic, functional, constructive, material and cultural values. The choices to re-use and repair are seldom unambiguous.

Although several cases can be described, we picked out two buildings: the rehabilitation of the flour-mill *Vuurmolen* (1902) and the warehouse *Depot Royal* (1903-6). These cases give us the opportunity to highlight the various systems of reinforcement that were applied in these early times. They point out, that although the Hennebique system was internationally known by then, the buildings constructed according to it, were still connected to the local habits and expertise in some way.
By going into the architectural and technical details of the renovation of these two surviving early reinforced concrete industrial buildings we analyse the re-design process by raising the following question: how can we conserve the characteristic concrete details while upgrade the building to the modern standards?

VUURMOLEN, 1902

Construction of the mill

The flour-mill at Overijse (a city near Brussels) is said to be the oldest surviving industrial building in Belgium with a frame of reinforced concrete (Vande Putte, 1984). The freestanding mill building, also called *Vuurmolen*, situated near the city centre, counts five levels, each approximately 3 m high. The mill is built up with concrete slabs, primary and secondary beams which rest on columns.
Neither original plans nor drawings of the building are preserved, but one can base on early construction photographs to date back the building and gain insight into the used reinforcement system. A photograph with hand drawn date 21 June 1902 shows the developer, Mr. Decoster, between the building workers on the building yard (Fig. 1). The photograph shows the footprint of the building which measures 17.5 m by 9 m. The dense structural grid of primary and secondary beams is visible (1.50 m by 3.50 m). At the moment the picture was taken, the concrete slab has been poured and workers are setting up the timber formwork around the reinforcement of the inverted foundation beams. Although the pictures do not show the reinforcement in detail, the diagonal stirrups strips catch the eye. This arrangement of the reinforcement comes close to the patented system of the engineer Maurice Dumas. And indeed, the hardly visible text on the board in the photograph mentions: … *STEVENS DECOSTER, BETON ARME SYSTEME PERRAUD DUMAS, LEON MONNOYER CONSTRUCTEUR, BRUXELLES* (Ackers, 2005, p. 142).

Engineers Perraud & Dumas and constructor Monnoyer

In a way the entrepreneur *Monnoyer* as well as the engineers *Perraud & Dumas* were connected to Hennebique. In 1895 Hennebique built a flour-mill in Nantes for the engineer and industrialist Perraud. Four years later, in 1899, Perraud is the engineer who coordinated the construction of the *nouvel Hotel Communal* in *Saint-Gilles (Brussels)* designed by the French architect Albert Dumont. The reinforced concrete slabs, built according to the Hennebique system, are constructed by the entrepreneur *Leon Monnoyer* (Baes, 1931).
Later on Perraud and his brother in law, the Frenchmen Maurice Dumas, got a licence in Brussels for the system Hennebique. In 1902, to become independent from Hennebique, they founded the reputed Brussels engineering office *PERRAUD & DUMAS ingénieurs civils* and took a patent on a reinforcement system with inclined reinforcing bars: '*trussing arrangement for iron and cement constructions*' (Dumas, 1903). From 1904 onwards Dumas took over the lead of the office. The office *Perraud & Dumas* built important and innovative constructions. Next to the architect Albert Dumont, they worked together with the Belgian architect Paul Jaspar on his masterpiece, the *Salle de la Renommée* in Liège in 1905. This hall is covered with three concrete cupolas that serve as an early example of the use of concrete shells. When engineer Dumas got sick in 1911, he was succeeded by engineer Braive, but only for a short time, as in 1913, the *Société d'enteprises Monnoyer et fils* took over the office. The *Société d'enteprises Monnoyer et fils* had been working together for many years with this engineering office. In 1906 for example, Monnoyer patented his system '*Reinforced concrete structure*' which consisted of prefabricated building elements to construct in a fast way chimneys. The calculations for this patent had been optimized by the engineers Dumas and Braive (Baes, 1931). According to the patent, Dumas was at that time a subject of the King of Belgium (Dumas, 1909).

Patent Maurice Dumas

In his patent '*trussing arrangement for iron and cement constructions*', sent to the United States Patent Office in June 1902, the inventor Maurice Dumas, at that moment citizen of the French Republic, residing at Brussels, describes the different parts of his lattice formwork. Figure 2 shows his patent and the arrangement of the reinforcement in a simple beam. Dumas distinguished five kinds of bars. The main guide-bar (assigned the letter *a* in fig. 3), a round bar, runs trough the whole length of the beam and takes up the tension forces. If necessary, additional longitudinal bars (b, c, d, f, g) can be placed into the tension and the compression zone of the concrete beam to furnish the necessary resistance. Flat strips (j) are wound around the main guide-bar to form the trellis-work. Close to the support, the distance between the strips decreases to resist the shear forces.
It is surprising that Paul Christophe does not record the system Dumas in his handbook '*Le béton armé et ses applications*'. On the other hand, the communication letters from Paul Christophe and Maurice Dumas to the secretary of the technical journal *Annales de travaux publics de Belgique*, reveals the tension between both prominent engineers (Christophe, 1902) (Dumas, 1902).

Figure 4: Vuurmolen. Building site during renovation 2003 (left). Exposure of the reinforcement in the primary and secondary beam and in the slab (right).

Figure 5: Vuurmolen. Strengthening of the beams and columns of with CFRP layers (left). Lowered ceiling after renovation in 2008. Columns and beams are plastered. (right).

In 1902 the engineering office *Perraud & Dumas* was also working on the building *Algemeen Handelsbladgebouw* in Amsterdam. The construction drawings of this building, dating back from the period June - October 1902, are still available in the City Archives of Amsterdam. These drawings are an interesting source to gain insight into the way Perraud & Dumas designed and detailed their early reinforced concrete components (slabs, beams and columns).

By removing the cracked concrete from the primary beams in the Vuurmolen, one could determine the diameters of the bars (De Schutter, 2001). Using the same terminology as in the patent of M. Dumas to describe the construction, the main guide-bar (a) has a diameter of 20 mm. As on fig. 2, two bars are placed next to each other. The additional bars (b, c) are positioned on top of the guide-bar. They have a diameter of 12 mm. The secondary beam, also doubled, has a guide-bar of diameter 16 mm. No additional bars are applied here. The strips (25 mm by 2 mm) are positioned every 25 cm. At the supports, the field with increased strips is small, in fact only the last field has one additional strip, leading to an intermediate distance of 10 cm. As a consequence the resistance to shear force in the area of the supports is limited. The visual inspection of the beams indeed revealed the typical crack pattern for shear failure (De Schutter, 2001).

Evolution of the mill

In 1903 the modern grinding equipment delivered by the German firm *Mühlenbau Gebrüder SECK* was installed, but only from 1905 onwards, the grain mill was ready for use. In 1922 *Stevens and Decoster* sold the mill to *Desadeleere and Rémy*. They added two storage buildings, in brick and timber, at the left side and electrified the production process. Around 1950, the former machine hall, situated at the left of the building, was replaced by a silo building. In 1957 already, the mill activities stopped. After a long period of neglect the abandoned mill was bought by the council of Overijse in 1997. The council organised an architectural design competition to bring over the administrative centre of Overijse to this building site. The architecture office *A2D & partners* won the competition in 1999. The Brussels architect Barbara Van der Wee was appointed to follow up the restoration of the 1902 concrete building, which was listed as a historical monument since 1980.

Refurbishment

The refurbishment of the three industrial mill buildings, dating back from 1902, the 1920's and the 1950's, into administrative centre was not evident. Not only because the program asked for more space then there was available in the existing buildings, but especially because the circulation inside the building was not suited for other than industrial functions. Opening up the building to the public included tightened regulations concerning the accessibility and fire safety. The structure of the reinforced concrete building would have changed drastically if one would have tried to insert accurate circulation into this volume. The decision to open up the backside of the building and add a new construction to provide the circulation, made it possible to preserve the listed building and conserve the characteristic façade (Fig. 3, 4).

Structural repair and strengthening

Due to the neglect of the building during almost 40 years, the structural elements were in a very bad state. Material tests on the concrete slabs showed that the carbonated depth passed beyond the reinforcement. On several places the concrete had been pushed off due to the corrosion of the reinforcement. The compression tests revealed that the quality of the concrete was very poor: a characteristic compressive strength of only 7 N/mm^2. The addition of a sixth level and the function shift to offices initiated higher loads on the floor slabs and the columns. This fact, together with the poor condition of the structure led to the decision to intensively strengthen the slabs, beams and columns.

The damaged or missing reinforcement and concrete was first repaired. Close to the supports, the beams were covered with carbon fiber reinforced plastic (CFRP) to increase the resistance against shear (Fig. 5). The bending resistance at mid span of the beam was increased by gluing a steel plate underneath the beams. While strengthening, attention was paid not to hide the original characteristic geometry (corners) of the beams and columns. The columns were wrapped in CFRP layers to increase the axial capacity. Additional steel strips were applied to increase the resistance to bending induced by wind loading. The concrete slabs are strengthened with a new lightweight concrete deck, which works as an extended compression zone, fixed to the existing beams with dowels (Winey, 2006).

Thermal insulation

The cement plastered façade and the characteristic steel windows had to be conserved. To upgrade the thermal capacity of the wall, which was constructed as a concrete frame with brick infill (Fig.2), insulation boards were attached to the inside of the wall. A second window is placed at the inside of the original steel window. To reduce the thermal bridge close to the concrete floor slab, a horizontal thermal insulation board is fixed onto the ceiling, into the first bay. On top of this, an acoustic insulation board is applied. This way, the level of the ceiling is lowered and the proportions of the primary and secondary beams get lost, leading to a somewhat estranged experience (Fig. 4b, 5b). However, from outside the intervention of the thermal upgrading is (almost) invisible.

ENTREPOT ROYAL AT TOUR & TAXIS, 1903-6

Construction

In the 1890's Brussels was looking for a place to built a new seaport quarter. Their eye felt on a piece of land outside the city walls. The 37 ha large plot, once owned by the family Von Thurn und Tassis, later called Tour & Taxis, was situated next to the canal, the railway and important roads. The buildings erected on this site (the maritime station, the hotel for administration, the Entrepot Royal, the storehouses, a.o.) are all masterly examples of engineering: when walking in the buildings one can admire the enormous spans, the beauty of the steel trusses, the elegance of the concrete spans. When leaving the building, on the contrary, this engineering beauty is hidden by brick façades. This need to hide the structure reveals that there was still a long way to go before reinforced concrete was recognized by architects not only as a structural interesting, but also as a beautiful and inspiring material (Fig 6).

Figure 6: Warehouse Tour&Taxis. Inside and outside view after rehabilitation (Project T&T)

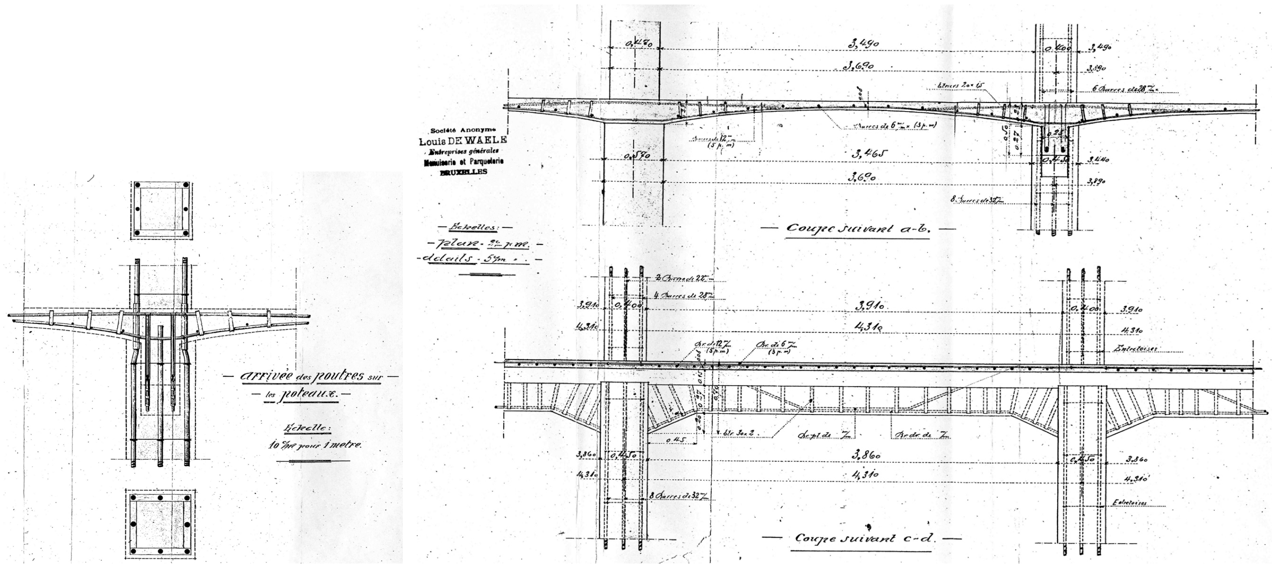

Figure 7: Warehouse Tour&Taxis. Construction details of the reinforcement by François Hennebique: column (left) and arched floors (right) (Archives n.v. Zeekanaal en Haveninrichting)

Figure 8: Warehouse Tour&Taxis. Inside view in the storage rooms before renovation (1998). The vaulted reinforced concrete floor slabs are supported by beams and columns.

We focus on the warehouse *Entrepot Royal* on the site of Tour&Taxis, designed by Architect Van Humbeeck and engineer Jules Zone. In fact, it was the third time that Brussels had to expand and move the location of its warehouse. The first warehouse was built in 1781, but soon became too small and was rehabilitated into the Flemish Theatre in 1883. The second warehouse, built in 1842-7 by architect Henri Spaak was the first ‘fireproof’ building in Belgium erected with brick vaults and cast iron beams and columns (Wouters, 2006). It is not surprising that the harbor authorities approached Hennebique, who strongly promoted the fireproof resistance of his reinforced concrete structure, to build the third new warehouse. The similarities between the construction of the second and the third warehouse are remarkable as will be explained in the next paragraph.

System Hennebique

In 1903 the construction contract for the *Entrepot Royal* was awarded to the Belgian building contractor *Société Anonyme Louis De Waele*, who was a concession holder of the system Hennebique since 1892. By late 1906 the building was completed.
The warehouse, 180 m long and 60 m wide, has a simple lay-out. The train wagons could enter the building trough the central hall. The storage rooms were organized around this hall, five stories high. Every floor had 18 storage rooms, each about 20 m by 21 m, which could be reached via cantilevered galleries. Steel footbridges, crossing the atrium, improved the circulation inside the building block.
All the construction plans and even the calculation notes are conserved by the harbor authority *n.v. Zeekanaal en Haveninrichting*. The floors are built up with reinforced concrete slabs (Fig. 7). The slabs are not designed as a two-dimensional plate, but as flat arches, spanning 400 cm. The thickness of the reinforced concrete arch increases from 8 cm in the middle to 29 cm at the ends. The beams span 430 cm and rest on concrete columns.
These construction details remind the 1842-7 warehouse which was built with brick arches spanning 375 cm, with a thickness increasing from 30 cm in the middle until 78 cm at the ends, resting on cast iron beams with a span of 610 cm. Therefore, the advantage of building in reinforced concrete (compared to brick vaults) does not lie in the increasing of the span of the beams but in the slenderness and lightness of the floor.
The dimensions of the columns increase from 20 by 20 cm on the upper floor to 55 by 55 cm in the basement. The applied diameters of the reinforcement bars go from 40 mm in the basement columns over 38, 32, 28, 22 to 16 mm in the upper columns. The floors were designed to stand heavy loads (10 kN/m²) since all kinds of merchandise had to be stocked.

Rehabilitation

The warehouse was built for long-term storage of goods under customs control but not liable to duties. The thick walls and dim light provide excellent conditions for conservation. However, in 1987, the building was abandoned as it no longer met modern requirements for rapid transit and transshipment (Vanderhulst, 2008).
The large structural grid (400 x 430 cm) and the high load capacity create many possibilities for re-use. Nevertheless, the small window openings and the fire safety design of the atrium need special attention. Being part of a large sea port quarter, the rehabilitation of the complex took a long time since one insisted on a global vision on the site and there was much resistance from the local residents. In 2001 *project T&T* together with *Archi 2000* architects rehabilitated the *Entrepot Royal* into offices. On the ground level an interior street with shops and restaurants is located. (Fig 6b)

Structural repair

Since detailed information about the reinforcement was available, one only had to check whether this information was in accordance to the built construction. The visual inspection of the building revealed no serious problems. Particularly on the upper floor, where water infiltration leaded to corrosion of the reinforcement, concrete had been pushed off. Since the new function imposes smaller forces to the building than the original one, the structural intervention could be reduced to the repair of damaged areas.

Thermal insulation

The 47 cm thick outer brick walls are load bearing. Due to the impressive eclectic façade in brick and stone, intervening at the outside to upgrade the thermal insulation of the external walls was not an option. Working at the inside on the other hand, would introduce thermal bridges. Taking into account the massive walls and the geometry of the building, the architects decided to intervene only in the roof and the windows. The architects wished not to disturb the aspect of the raw brick walls and the characteristic vaulted concrete ceiling, so electricity, plumbing and the heating and ventilation system were integrated in a new raised floor.

DISCUSSION AND CONCLUSION

When the qualities of the historical monument are determined, the design team will try to conserve the characteristics while upgrading the building to the new standards required by the new function. Since these demands are conflicting, the design team has to make decisions which are based on architectural as well as on technical facts, leading to diverse solutions.
A renovation asks for the comprehension of the significance of the monument and a present-day interpretation. A new identity has to be created for an abandoned space. The right balance has to be achieved between the values of the monument on the one hand and the technical interventions on the other hand. Only a well-considered economical and cultural function will secure the long term survival of the historical monument. There are no unequivocal procedures to conserve the early reinforced concrete structures because

these industrial monuments are too multiform in character and meaning. Each monument requests an exclusive approach and treatment.

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