Reinforced concrete construction and the technical design of urban buildings in *Belle Époque* France and Belgium (1892-1914)

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Abstract

The principal outcome of this doctoral thesis is a historical mechanism which describes a flow process for technical design and its application to construction, as well as associated attributes of the key specialist professionals who were involved in the use of a novel materials-system more than a century ago. The mechanism is designed to help describe the influence of innovative reinforced concrete and cement systems on the design and construction of non-monumental, urban buildings during the final decades of the *Belle Époque*, in and near the major francophone cities of Paris, Lille and Brussels.

The change in construction technology is interpreted as the second stage of a metallic building design revolution that took place between 1892 and 1914, derived from the increased use of iron and then steel in nineteenth-century urban construction in France, particularly its capital city. The first stage of this metallic building design revolution had culminated in the monumental 'temporary' works of the steel and glass *Galerie des Machines* built for the triumphant 1889 *Exposition Universelle* in Paris. Then, in the early 1890s, a transition took place into the second stage of the revolution. The French inventor François Hennebique (1842-1921) was an adopted Belgian whose *béton armé* system of reinforced concrete was technically codified between 1892 and 1897 in a series of more sophisticated industrial patents – this was in parallel with other innovative approaches that together contributed to the creation of early industrial standards for the novel materials-system. *Belle Époque* architects, engineers and contractors became receptive to the use of new reinforced concrete and cement systems in their works, converting building commissioner needs into key structural requirements for the design and construction of non-monumental, urban buildings. The novel materials-system would be used to construct fire-resistant and structurally efficient manufacturing premises, warehouses, banks and apartment blocks. Many of these buildings allowed more natural daylight to penetrate inside by a more widespread and effective use of glazing, through large windows, skylights and, in one case, a cupola. A French form of the North American 'daylight factory' conventionally associated with Henry Ford's massive car plant near Detroit could be distinguished. A number of buildings also displayed new forms of highly decorative ceramic cladding on their street facades, both to protect and to hide the less aesthetically pleasing concrete structure behind them. Residential housing became cleaner and more affordable, moving away from the crowded, disease-ridden city slums of old.

During the second stage of the metallic building design revolution, architects and engineers developed their confidence and abilities in envisioning the novel materials-system through the technical design aspects of their work. Together with contractors, they acquired the specialist skills needed to apply this to building projects, ensuring that the completed structures reflected the original design intentions, in an acceptable balance between technology and aesthetics. Specialist contractors managed the risks associated with using an innovative technical approach to urban construction.

The creative design freedoms expressed in the *Art Nouveau* genre of the eclectic approach that dominated *Belle Époque* architecture came to an end with the outbreak of the First World War. Once peace had been reinstated after the extensive human and material devastation experienced in Northern France and Belgium, the postwar period saw an increasing dominance of a plainer industrial approach to urban architecture; this was evangelised by the Swiss architect Charles-Édouard Jeanneret, better known as Le Corbusier (1887-1965), the German architect Walter Gropius (1883-1969), and their International Modernist peers around the globe.

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L'aboutissement principal de cette thèse de doctorat est un processus historique (« historical mechanism ») qui décrit la conception technique et son application à la construction, ainsi que les caractéristiques des principaux professionnels spécialisés impliqués dans l'utilisation d'un système de matériaux novateur il y a plus d'un siècle.

Le processus est conçu pour aider à décrire l'influence d'approches innovantes utilisant le béton et le ciment armé dans la conception et la construction de bâtiments urbains non monumentaux au cours des dernières décennies de la Belle Époque, dans et à proximité des grandes villes francophones de Paris, Lille et Bruxelles. Le changement de technologie de construction est interprété comme la deuxième étape d'une révolution dans la conception d'un bâtiment métallique qui a eu lieu entre 1892 et 1914, découlant de l'utilisation accrue du fer puis de l'acier dans la construction urbaine du XIXe siècle en France (la première étape de cette révolution), en particulier sa capitale.

La première étape de cette révolution a culminé dans l'œuvre monumentale « temporaire » de la Galerie des Machines construite pour l'Exposition Universelle de 1889 à Paris. Puis, au début des années 1890, une transition s'est déroulée dans la deuxième étape de la révolution. L'inventeur français François Hennebique

(1842-1921) était un Belge d'adoption dont le système de béton armé a été techniquement codifié entre 1892 et 1897 dans une série de brevets industriels plus sophistiqués – parallèlement à d'autres approches qui, ensemble, ont contribué à la création des premières normes industrielles pour le nouveau système de matériaux. Les architectes, les ingénieurs et les entrepreneurs de la Belle Époque sont devenus réceptifs à l'utilisation de nouveaux systèmes de béton et de ciment armé dans leurs travaux, transformant les besoins des clients en exigences pour la conception et la construction de bâtiments urbains non monumentaux.

Le nouveau système de matériaux est utilisé pour construire des locaux de fabrication résistants au feu et structurellement efficaces, entrepôts, banques et immeubles d'habitation. Beaucoup de ces bâtiments permettaient à plus de lumière naturelle de pénétrer à l'intérieur par une utilisation plus généralisée et plus efficace du vitrage, grâce à de grandes fenêtres, des lucarnes et, dans un cas, une coupole . Une forme française du « daylight factory » nord-américaine conventionnellement associée à une énorme usine Ford d'automobiles près de Detroit est apparue. Un certain nombre de bâtiments également présentent de nouvelles formes de revêtements céramiques très décoratifs sur leurs façades de rue, à la fois pour protéger et pour cacher les structures moins esthétiques en béton armé. Le logement résidentiel est devenu plus propre et plus abordable, en déménageant loin des bidonvilles surpeuplés et infestés de maladies. Les architectes et les ingénieurs ont appris à faire confiance à leurs capacités d'imaginer le nouveau système de matériaux à travers les aspects techniques de leur travail. En collaboration avec les entrepreneurs, ils ont acquis les compétences spécialisées nécessaires pour les appliquer aux projets de construction, s'assurer que les structures terminées reflétaient les intentions de conception originale, dans un équilibre acceptable entre technologie et esthétique. Ces entrepreneurs ont géré les risques liés à l'utilisation d'une approche technique innovante de la construction urbaine.

Les libertés de conception créative exprimées dans le genre Art nouveau de l'approche éclectique qui a dominé l'architecture de la Belle Époque ont pris fin avec le déclenchement de la Première Guerre mondiale. Une fois la paix revenue après les importantes destructions humaines et matérielles qu'a connues le Nord de la France et la Belgique, la période d'après-guerre se caractérise par la domination croissante d'une approche industrielle plus simple de l'architecture ; ceci a été évangélisé par l'architecte suisse Charles-Édouard Jeanneret, plus connu sous le nom de Le Corbusier (1887-1965), l'architecte allemand Walter Gropius (1883-1969) et leurs contemporains modernistes internationaux dans le monde entier.

Contents

Introduction

> Because, unlike literature, architecture is by necessity an art of luxury, it is in this latter domain that it will produce a difference. Let us leave aside the subtle nuances between architectural styles, depending on whether to attach oneself to the opulent character of an openly *nouveau riche* taste, more or less distinguished from *Art Nouveau*, or affirming a greater attachment to *Louis XVI*, much more fitting and probably better raised … The art of the *Belle Époque* is that of the parade of money - emphatic solemnity around a few shared ceremonies, such as horse racing, a walk in the *Bois de Boulogne* or expeditions to the countryside ...[1]

The historic setting

The French Third Republic (1870-1940) saw major artistic, technological and political changes encompassed within a largely peaceful period of the late nineteenth and early twentieth centuries that ended abruptly in 1914 with the outbreak of the devastating First World War. The optimistic label applied to this period retrospectively was the *Belle Époque*. As François Loyer indicates in the above quotation from *Le Siècle de L'Industrie*, this was a time associated with free expression in architecture and the decorative arts, in turn connected to the rise of Impressionism and even more avant-garde derivatives in the fine arts. The period saw the emergence in the 1890s of an *Art Nouveau* genre of architecture within a broader flourishing of contrasting styles, many derived from historical examples, collectively termed *Éclectisme*. The Belgian architect Victor Horta (1861-1947) completed Hôtel Solvay in Brussels in 1894 (Figure 0.1), an urban building whose interior in particular represented many aspects of the more radical approach, expanded on by French architect Hector Guimard (1867-1942) for his distinctive Castel Béranger in Paris completed the following year.

[1] François Loyer, *Le Siècle de L'Industrie* (Éditions d'Art Albert Skira, 1983), 216. « Parce que, contrairement à la littérature, l'architecture est par nécessité un art du luxe, c'est dans ce domaine qu'elle va cultiver la différence. Laissons de côté les nuances subtiles entre styles de référence, selon qu'on s'attache au caractère cossu d'un goût ouvertement nouveau riche, plus ou moins démarqué de l'Art Nouveau, ou qu'on affirme la bonne tenue d'un Louis XVI, nettement plus convenable et sans doute mieux élevé … L'art de la Belle Époque est celui de la parade de l'argent - solennité emphatique autour de quelques cérémonies mondaines, comme le retour des courses, la promenade au Bois de Boulogne ou les parties de campagne ... ».

Figure 0.1. Hôtel Solvay, Brussels today (Horta, 1894). (Nick von Behr) It was an example of Art Nouveau architecture with organic iron decoration on the facade and in the interior, one facet of creative expression during the Belle Époque.

There was much debate during the *Belle Époque* about the significance of these artistic developments, together with associated technological change, for the design and construction of buildings, and this is captured within the final section of the thesis. The second stage of a metallic building design revolution ‘started’ in 1892-3 with the lodging in Belgium and France of key industrial patents, exemplified in the design and construction in and near the three *Belle Époque* cities that were Paris, Lille and Brussels of non-monumental, urban buildings employing a novel materials-system. This was reinforced concrete, in effect formed concrete or cement with iron or steel internal reinforcement. The specialist designers and constructors of these buildings were architects, engineers and contractors, sometimes combined into a single person or organisation, with a sufficient confidence and expertise in the novel materials-system. The professional actors' inter-relationship was one of both 'sibling' rivalry and cooperation, since they needed to work as a co-ordinated design and construction team with those who commissioned these new buildings; in some cases, a design and construction specialist *was* either the commissioner or a close relative of his.

The unique contribution of the thesis to existing research

The approach of the thesis is novel, principally, in that it produces systematically across technical, societal and building design contexts, a new historical mechanism that is used on a significant non-monumental urban *Belle Époque* building (the *immeuble* at 25b rue Benjamin Franklin in Paris (1904) by the Perret brothers); this helps us to understand better the relationship between technology and aesthetics when designing and constructing with the novel materials-system that was reinforced concrete and cement, at a critical stage in its initial development.

The conception of the thesis derived from the researcher's project for a Masters in the History of Technology at the University of Bath on the 'dockisation' of the River Avon in Bristol, which examined the professionalisation of Victorian dock engineers when operating in a technically challenging estuarine environment.[2] Further thinking since then developed into the skills progression of nineteenth-century design and construction professionals, exemplified by outstanding figures such as the British civil engineers Sir John Wolfe Barry (1836-1918) and Henry Marc Brunel (1842-1903), both sons of famous fathers. The core research question for this thesis transitioned from a focus on the role of key British individuals, to a systems-based approach that sought to better understand historical events shaping wider materials and processes within the field of international construction history. The core research question is therefore stated as follows: 'What was the influence of novel reinforced concrete and cement systems on non-monumental, urban building design in and near three *Belle Époque* cities?'

The historical construction activity described in the thesis was set within a framework of codifying technical knowledge that included industrial patents, structural specifications and technical guidance, together forming what are termed 'early industrial standards' for the novel materials-system – an original approach taken in this thesis to describing the gradual normalisation of an emerging metallic construction technology that

[2] Nicholas von Behr, 'The "dockisation" of the Port of Bristol' (University of Bath, 1995).

constituted more than one building material. Of these three components of early industrial standards, industrial patents encapsulated the state of technical knowledge, at a given point in time, of the key inventors of new reinforced concrete and cement systems. François Hennebique was the 'master' amongst these, whose life story captured flows of technical innovation between Belgium and France that accompanied parallel aesthetic exchanges about *Art Nouveau* architecture.

Hennebique was born in Northern France in 1842 and moved to Belgium as a young adult, where he set up his contracting business and sought clients for his novel *béton armé* system back in his home territory; he finally settled in Paris where his global headquarters were based from the mid-1890s onwards. Hennebique, his *béton armé* system and his business have been much studied since the 1980s, after the surviving organisation's archives were donated to the French State.[3] The present research, while building on these firm foundations, extends to other new reinforced concrete and cement systems; it also uses the lens of technical (Section 1), societal (Section 2) and building design (Section 3) contexts for the collective novel materials-system, connecting it to a network of French and Belgian actors who were involved with its development and maturation as a generic body of technical knowledge in the construction of new buildings.

The research highlights new perspectives on evidence about historic buildings in the northern part of France, and to a lesser extent in neighbouring Belgium. A case study in Chapter 1 of the since-demolished Bossut-Masurel textile factory warehouse in Roubaix, near Lille completed in 1892, indicates that it was probably one of the first buildings to use a truly innovative version of François Hennebique's *béton armé* system, patented in both Belgium and France during 1892-93. This indicated an emerging link between new building design approaches and early industrial standards for the novel materials-system. The key document evidencing this is the original technical workbook for the structural design calculations of the warehouse, signed by Hennebique himself in 1892 and still held at the *Centre d'archives d'architecture contemporaine* (CAAC) in Paris. We know that the French inventor only made this document available for others to peruse several years later, probably

[3] Patricia Cusack, 'François Hennebique: The Specialist Organisation and the Success of Ferro-Concrete: 1892-1909', *Transactions of the Newcomen Society* 56, no. 1 (1984): 71–86; Patricia Cusack, 'Agents of Change: Hennebique, Mouchel and Ferro-Concrete in Britain, 1897-1908', *Construction History* 3 (1987): 61–74; Gwenael Delhumeau et al., *Le Béton En Répresentation. La Mémoire Photographique de l'entreprise Hennebique 1890-1930* (Éditions Hazan, 1993); Gwenael Delhumeau, *L'invention Du Béton Armé : Hennebique, 1890-1914* (Norma, 1999); Stephanie van de Voorde, 'Bouwen in Beton in België (1890-1975) Samenspel van Kennis, Experiment En Innovatie' (University of Ghent, 2011); Armande Hellebois, 'Theoretical and Experimental Studies on Early Reinforced Concrete Structures' (Universite Libre de Bruxelles, 2013).

after he felt secure enough about the technical and commercial advantages he had acquired over his growing competitors, though he would never be entirely satisfied about this.

The research also illuminates an expanding knowledge base in the history of nineteenth- and twentieth-century construction technology and associated architectural facets. Hence, an investigation of the North American architectural typology of the reinforced concrete 'daylight factory', which may have at least partly originated in Northern France. A case study provides an insight into the connection between the employment of the novel materials-system in vast glazed, monolithic factories, such as Henry Ford's gigantic Highland Park complex near Detroit, and what was being observed first-hand from primary sources about historic industrial buildings in Northern France. As for the subsequent trope that emerged from the 'daylight factory' architectural typology, this was associated with Le Corbusier, Gropius and their International Modernist peers; the ideas behind it flitted back and forth across the Atlantic until it became part of a wider myth associated with the broader merits of an urban industrial architecture that took hold globally in the interwar years.

A historical mechanism

A key output of the thesis is a historical mechanism designed to help answer the core research question, 'What was the influence of novel reinforced concrete and cement systems on non-monumental, urban building design in and near three *Belle Époque* cities?' Rather than appearing at the start of the thesis as a hypothetical framework to be tested against evidence, the historical mechanism is produced gradually across the three sections of the thesis, beginning with the technical context, supplemented by the societal context and finalised within the building design context. Subsidiary research questions frame all three sections of the thesis and connect them, and therefore also the production of the historical mechanism, to the core research question which is answered in the Conclusion. This appeared to the researcher to represent the most effective methodological approach to the thesis.

The historical mechanism is produced by testing the potential significance of a wide range of mainly nineteenth-century historic example buildings, all designed and constructed using metallic systems that included wrought and cast iron, steel and reinforced concrete and cement (see the full list in the Appendices). Process tracing, a social scientific approach to identifying causation described in the research methodology, was thus applied through the analysis, including by using case studies, of historic example buildings within: a technical context for *Belle Époque* construction (see Section 1); then a societal context for *Belle Époque* construction (see Section 2); and finally a building design context for *Belle Époque* construction (see Section 3). As part of finalising the historical mechanism, two typologies of non-monumental, urban building are created and compared: firstly, an Urban Industrial typology that captures the industrial aspects of six historic example buildings from the case studies in the thesis; and secondly, an Urban Housing typology that captures the housing aspects of a further six historic example buildings from the same case studies. The historical mechanism therefore contains components and sub-parts that relate to key information blocks and their details in the three sections of the thesis – at the end of Section 1 these are visualised using a schematic for the technical context, which is then expanded at the end of Section 2 to include both technical and societal contexts, suggesting a possible flow process. Section 3 contributes the final details of the historical mechanism from a building design context and confirms the arrangement of the flow process and the key components. As with any knowledge (re)codification process, indeed very much like the creation and review of technical standards and their key components that continues to this day, the historical mechanism is created by processing new, as well as existing evidence, from which an improved output is produced.

The historical mechanism's ability to help answer, even at least partially, the core research question is validated after using it with a further non-monumental, urban building not included in the case studies or the two typologies: this is the much cited *immeuble* at 25b rue Benjamin Franklin in Paris, completed by the Perret brothers in 1904 using a derivation of Edmond Coignet's reinforced cement system. This application of the historical mechanism to this *immeuble* confirms that the professional attributes of the architect-engineer-contractor teams involved was a key factor determining the extent of influence of the novel materials-system on *Belle Époque* building design and construction. These specialist professionals designed and constructed using the new reinforced concrete and cement systems with growing levels of technical confidence and skill, ensuring that the final building reflected the original design intentions. Related to this last professional attribute was the need for contractors to perform the role of an intermediary between the 'sibling' specialist professionals, by managing acceptable levels of project risk given the challenges of the technical approach associated with the novel materials-system.

The modern day relevance of the thesis

The thesis indicates how the historical research described within it may have a bearing on contemporary technical building design, connected as this is to global environmental concerns that were never present during the period of the *Belle Époque*. It also points to possible further investigations into the influence of twentieth-century regulations on technical building design *after* the First World War; during the interwar years these regulations and linked codes of building practice developed into technical standards and guidance as we currently know them, not just for construction materials, products and processes, but with a greater focus on the expanding global professionalisation of the construction industry. All of this system currently operates through a network of international professional bodies, national and international Standards Bodies (with ISO as the world's Standards Body), as well as recognised global quality marks such as the 'Kitemark' or 'CE mark'. Any further research in this area would build on not only this thesis, but also on earlier doctoral research by, for example, van de Voorde on the historical use of concrete in Belgian construction, Angelino on developing better design standards for the construction industry and Melsens on twentieth-century Indian architects, engineers and builders.[4]

Terminology

The thesis contributes to a broader research debate about the historic role of innovative materials and systems for building design and construction, and novel combinations of these into materials-systems; all of this with specific reference to the early use of reinforced concrete and cement in more fire-resistant and structurally efficient non-monumental, urban buildings. Reinforced concrete and cement systems were composites of separate metallic and lithic materials, exploiting their combined strengths in a single materials-system – concrete is of a much more granular composition than cement, including a range of aggregates that are coarser than sand and similar 'fines', as they are commonly known. A materials-system is more than Antoine Picon's perfectly reasonable assertion noted in the Historiographic Framework, that reinforced

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[4] Voorde, 'Bouwen in Beton in België (1890-1975) Samenspel van Kennis, Experiment En Innovatie'; Mariapia Angelino, 'Developing Better Design Standards for the Construction Industry' (University of Bristol, 2019); Sarah Melsens, 'Architect, Engineer or Builder? A History of Professional Demarcation through Practice and Discourse, Pune (India) 1930-1992' (University of Antwerp, 2020). Future research could even connect to relevant lessons from the current revision of structural Eurocodes. https://eurocodes.jrc.ec.europa.eu/ (accessed 9/4/2024). See also Steve Denton et al., 'Eurocodes Evolution: Latest Developments and UK Approach', *The Structural Engineer*, March 2024, 12–14.

concrete and cement transitioned from a structural system into a single building material. However, for ease of language, the word 'system' is used when referring specifically to reinforced concrete or cement as a form of materials-system, or very occasionally the expression 'combined materials' if this helps to better describe the interrelationship between the different metallic and lithic components. The specific systems examined in the thesis are described fully in Chapter 1; the most significant one was the *béton armé* system invented by François Hennebique, in which specially-shaped steel rebars were incorporated within an externally formed concrete mass to create columns, beams and floors, all in an increasingly monolithic approach to design and construction.

Early industrial standards were a codified form of technical knowledge about a novel materials-system, such as reinforced concrete or cement systems. The term 'early industrial standards' includes three key components: a) industrial patents for the novel materials-system; b) structural specifications; and c) technical guidance. Industrial patents for the *béton armé* system were lodged by Hennebique at state offices in Belgium, where he was based until the mid-1890s, as well as in France, from whence he had originated and where he had identified important early users within the thriving Lille-Roubaix-Tourcoing textile industry, known as the 'Manchester of France'. Hennebique claimed not to be a great believer in patents, seeing them as necessary evils, but on the other hand he was more than willing to undertake expensive legal action to protect his intellectual property rights (described further in Chapter 1). The French inventor saw another key component of early industrial standards, structural specifications, as a part of the technical information about his *béton armé* system; hence the importance of the technical workbook for the Bossut-Masurel textile factory warehouse built in Roubaix in 1892, one of the earliest buildings to use Hennebique's patents (see the case study in Chapter 1). These structural specifications exemplified solutions to structural requirements (see Chapter 2), which were technical design responses to the building commissioner's need for a fire-resistant, structurally efficient and naturally lit structure at the heart of their combined industrial and commercial building. Structural specifications would have been used by an architect or engineer and the contracting team responsible for delivering the completed build to fit the original technical design intentions. Both structural specifications, as well as the remaining key component of early industrial standards, technical guidance, helped Hennebique and other interpreters of the novel reinforced concrete and cement systems explain the required specialist technical knowledge and skills to a wider network of construction professionals – this process is examined further in Chapters 4 and 6.

The influence of the novel materials-system on *Belle Époque* non-monumental, urban building design in France and Belgium is connected to the concept of the reception of architecture within its specific technological and cultural setting.[5] The time period of the *Belle Époque* spanned a metallic building design revolution, as the increasingly accepted employment of iron and steel in monumental urban settings transitioned towards the greater use of reinforced concrete and cement systems in non-monumental urban settings. It also saw a move away from a dominant eclectic approach to architecture, with its radically decorative *Art Nouveau* genre flourishing and then disappearing almost as quickly within the space of two decades, to an industrial-based approach that would later become associated with interwar International Modernism.

[5] In a more recent example of architectural reception, a debate on emerging postmodernist architecture was catalysed by a 1975 New York Museum of Modern Arts Exhibition on French *Beaux-Arts* technical and artistic virtuosity. Alice Thomine, 'Les Beaux-Arts au MOMA', in *L'architecture : la réception immédiate et la réception différée*, ed. Gérard Monnier (Éditions de la Sorbonne, 2006), 123–38.

Historiographic Framework

The historiographic review undertaken for the thesis showed how different disciplinary approaches to interpreting the history of buildings, ranging from the more technological to the more architectural, could be combined in research on the influence of reinforced concrete and cement systems on historic technical building design. A review of relevant secondary literature began in 2020 while the researcher was based at the University of Kent and continued throughout the research, analysis and drafting stages. A broad selection of research outputs in the UK and France provided valuable evidence for the technical, societal and design context for the thesis and helped rationalise an appropriate historiographic approach to the research. This is explained firstly by highlighting some key technological and engineering aspects of construction historiography; and subsequently by combining these with some key approaches from architectural historiography. The objective is to establish a suitable historiographic framework that, through relevant context and use of historic examples, ultimately produces a historical mechanism to help answer the core research question: 'What was the influence of novel reinforced concrete and cement systems on non-monumental, urban building design in and near three *Belle Époque* cities?'

The technological and engineering aspects of construction historiography

The thesis follows an interdisciplinary research approach within the broad field of construction history, which brings a number of academic disciplines together with professional and amateur interest around specific historic structures, building materials and construction systems.[6] Since construction history is both a relatively new and 'loose' interdisciplinary field, the academic constructs and theoretical models within it are still being developed. In his opening to the inaugural issue of *Construction History* in 1985, the respected architectural historian John Summerson described a key aspect of construction historiography relevant to a focus on a single materials-system – this was that the history of structural design could be separated into the study of consecutive innovations and their impact on practice (italics added for emphasis):

[6] During the first year of research an open database of international publications in construction history (IFCH Construction History Bibliography, accessible at https://www.constructionhistorybibliography.org/) was co-populated, reflecting the very broader interdisciplinary nature of the field. These disciplines include architecture, civil and structural engineering, the history of technological systems and the environment, historic building preservation, economic and social history, as well as some elements of business and legal history.

> You can study, for instance, the emergence of rational carpentry design in the seventeenth century, the entry of iron construction in the eighteenth or *the adoption of reinforced concrete at the end of the nineteenth. These are episodes involving theoretical development which found their way into building from out-side.* They are usually concerned with one material.[7]

A subsequent paper by Dunkeld in the same key journal within the field explained more substantially the state of play of the emerging interdisciplinary approach.[8] Somewhat unsurprisingly, he concluded that it defied any neat theoretical descriptions, but more helpfully referred to Groak and Ive on the implications of historical economic and technological changes in the building industry. They had outlined a wide range of theoretical approaches to analysing this topic, linked to their discipline of the economics of construction.[9] As will be seen, others have since added to these starting points[10], but any historiographic framework needs to operate within the context of an interdisciplinary corpus that centres on the past of the built environment, with possible implications for the present and future.

Looking specifically from the perspective of the historiography of technology, this researcher's disciplinary background, Picon amplified Summerson's description and suggested a gradual standardisation of reinforced concrete or cement as a building material:

> What does it mean to be hard, waterproof or durable? Each of these terms implies experiments, negotiation on the results of these experiments, normalization processes. It is through that kind of process that reinforced concrete, having at first been interpreted as a series of structural systems became gradually a material.[11]

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[7] John Summerson, 'What Is the History of Construction?', *Construction History* 1 (1985): 1.
[8] Malcolm Dunkeld, 'Approaches to Construction History', *Construction History* 3 (1987): 3–15.
[9] For example: "On the other side of this particular coin were the architectural theorists of 'modernism', who (by and large) were inclined to believe what they were told about this [building] industry 'frozen in time' but to promise that, with the utterance of the right formulae over the body of the unfortunate sleeping princess, all would be changed at once into the very epitome of progressive and radiant modernity." Steven Groak and Graham Ive, 'Economics and Technological Change: Some Implications for the Study of the Building Industry', *Habitat International* 10, no. 4 (1986): 125.
[10] A useful summary of construction history as a 'field' is to be found on the website of the Construction History Society: https://www.constructionhistory.co.uk/about-construction-history-society/construction-history/ (accessed 04/04/2024).
[11] Antoine Picon, 'Construction History: Between Technological and Cultural History', *Construction History* 21 (2005): 15.

In the rest of his paper Picon touched on the wider process by which novel building materials had emerged through invention, innovation and testing of new scientific and technical concepts. He highlighted the significance of historiography of technology that either explored the notion of structure as a cultural concept, or that took a social scientific technical systems approach when analysing past construction processes. This approach is more familiarly known as 'social construction of technology' (SCOT) and had been undertaken by Amy Slaton in her doctoral thesis and subsequent publication on the history of the early twentieth-century reinforced concrete factory building in the United States.[12] Slaton's approach was to relate a socially-oriented story of how the novel materials-system acquired a scientific and management status at the expense of the traditional craft skills in construction. This happened through: a standardisation process; the circulation of competing technical specifications; and the use of quality control associated with the developing specialist engineering profession. She saw this all reflected in the demand for plain, 'modern' industrial buildings that were replicated throughout the United States during the period of her study. In a similar SCOT vein, Deuten later used the development of reinforced cement and concrete in construction as one of a small number of, mainly European, industrial case studies illustrating a systematic social transition from localised to cosmopolitan technological knowledge; according to Deuten's hypothesis, French inventors of these new materials and systems, such as Paul Cottancin and François Hennebique, extended their business models using more explicit descriptions of their systems in patents.[13]

Turning to the historiography of engineering, Addis speculated on the historical nature of engineering design within construction in a conference paper summarising his original doctoral thesis of three decades before.[14] Addis had proposed a theoretical model adapted from the concept of major scientific paradigm shifts or revolutions put forward in the early 1960s by American philosopher of science Thomas Kuhn.[15] Addis assumed

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[12] Amy E. Slaton, 'Origins of a Modern Form: The Reinforced-Concrete Factory Building in America, 1900-1930' (University of Pennsylvania, 1995); Amy E. Slaton, *Reinforced Concrete and the Modernization of American Building, 1900–1930*, Kindle edition (Johns Hopkins University Press, 2001).

[13] Johannes Jasper Deuten, 'Cosmopolitanising Technologies : A Study of Four Emerging Technological Regimes' (Twente University Press, 2003), chap. 4.

[14] William Addis, 'Theory and Design in Civil and Structural Engineering. A Study in the History & Philosophy of Engineering' (University of Reading, 1986); Bill Addis, 'The Epistemology of Engineering Design as a Contribution to Construction History', in *Studies in Construction History: The Proceedings of the Second Conference of the Construction History Society*, ed. James W.P. Campbell et al. (Construction History Society, 2015), 3–10.

[15] Addis is not the first to apply Kuhn's theory to the history of technology, but his approach is distinctive and very much connected to both the history of engineering and the broader field of construction history: another

that an external crisis tripped an engineering building design community into a paradigm shift, amplified by an inability to respond sufficiently to changing inputs, influences and constraints. He outlined an engineering building design process that according to him had been used for centuries in construction and which was influenced by a range of external factors: the design climate; calculation techniques; building science; codes of design practice; construction methods; regulations and costs. Addis maintained, quite sensibly, that good *building design* engineers needed to be confident that their planned structures perform as specified, hence they employed a building design process to ensure this happens – he called this the 'Design Procedure' and further noted that it was defined by the knowledge and experience designers had, the specifications they passed to the builder or contractor, and the "nature of the justification they provide to ensure that the level of confidence in the proposed design is sufficient to commence building (the output of the Design Procedure)".[16] Addis has drawn a systems diagram which encapsulates this Design Procedure (Figure 0.2).

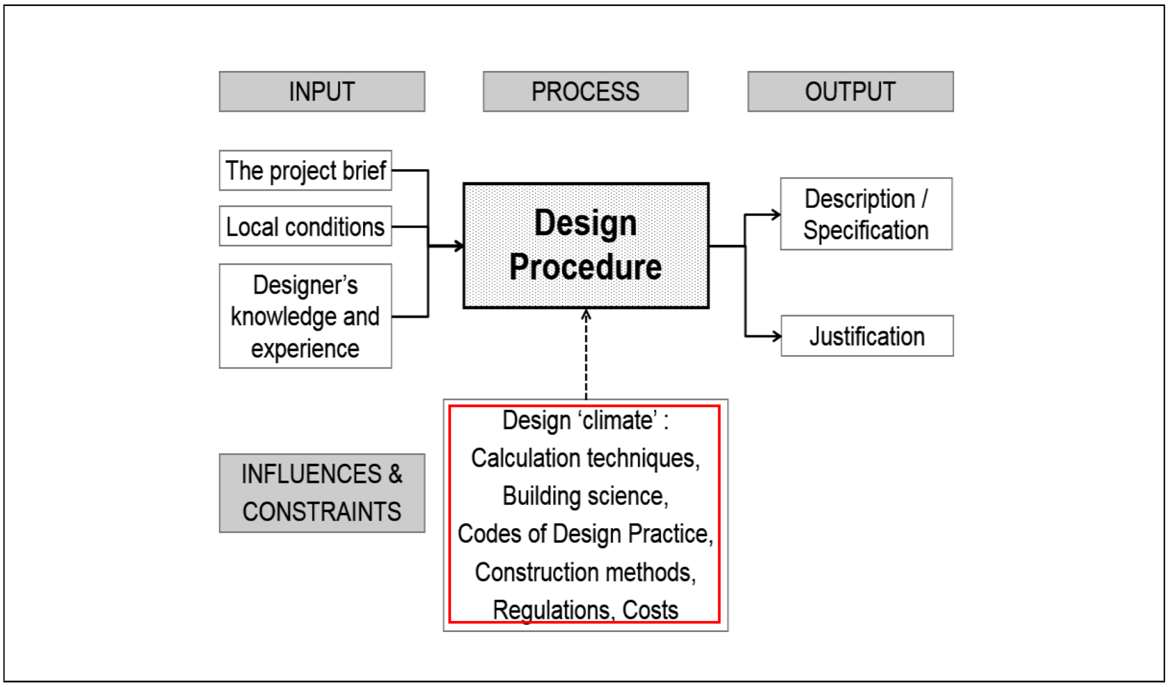

Figure 0.2: The Design Procedure highlighting influences and constraints. (Addis, 2015, p.4)

The systems diagram shows the inputs to and outputs from this process, as well as the previously mentioned influences and constraints that impact on any design freedoms (highlighted in the red box). The term 'early

more recent application of paradigm shifts in the subject area of this thesis is a collection of historical case studies (national, local and business) of the European development of Portland Cement and reinforced concrete. See: João Mascarenhas-Mateus, *Changing Cultures: European Perspectives on the History of Portland Cement and Reinforced Concrete, 19th and 20th Centuries*, 1st ed. (London: CRC Press, 2023).

[16] Addis, 'The Epistemology of Engineering Design as a Contribution to Construction History', 6.

industrial standard' is not specifically identified in Addis's Design Procedure model. The initial focus on the technical context of *Belle Époque* construction within Section 1 *is* on the role of early industrial standards, a more precise historical term for a technical standard during this period. It is composed of tightened descriptions of three of Addis's extraneous factors that influence or constrain the Design Procedure: industrial patents for the novel materials-system, structural specifications and technical guidance. Addis includes 'building science' within these factors, but to my mind this is an inadequate description of the physical components of a building, hence my preference for the term 'structural requirements'.

Using his Design Procedure, Addis goes on to explain how an analogous model for the emergence of new paradigms for engineering design might be postulated. Hence a community of 'normal' Design Procedures transforms into one of 'new normal' Design Procedures under the heading 'Design Revolutions' on the right side of Figure 0.3 below.

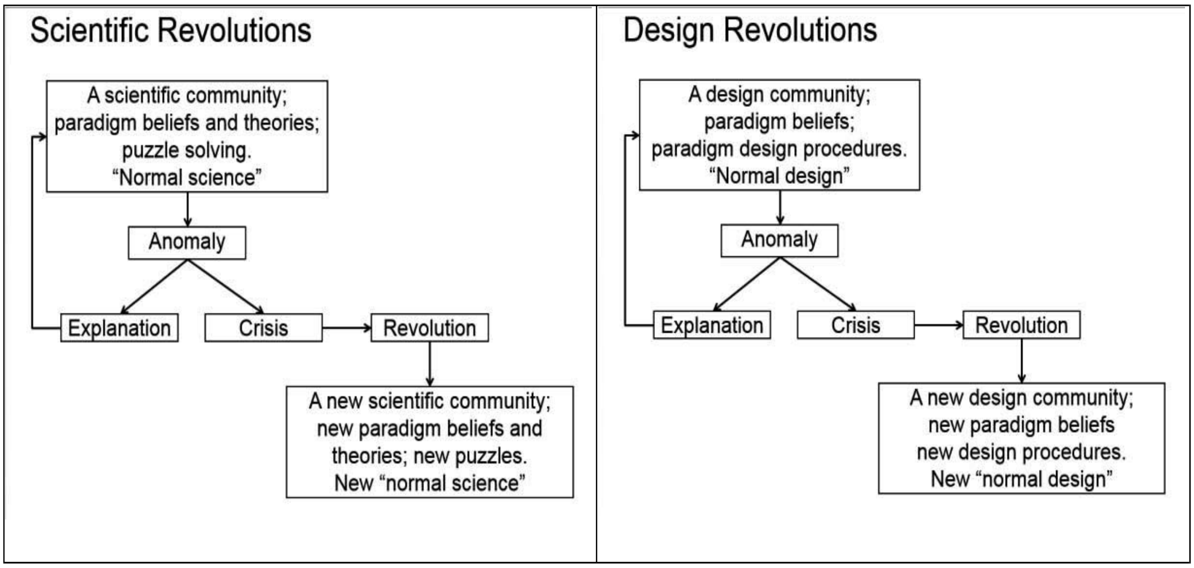

Figure 0.3: Diagram illustrating the analogous structures of scientific and engineering design revolutions. (Addis, 2015, p.8)

Addis's approach assumes that a type of intellectual crisis for which there is no satisfactory explanation, shifts the community of normal Design Procedures towards an abrupt transition or revolution; this crisis is therefore caused by the collective inability of building design engineers to respond sufficiently to multiple changing inputs, influences and constraints, all outlined in the Design Procedure diagram.

Traisnel had focused his own French-based doctoral research on an environmental history of buildings perspective, though with important architectural and building science elements to it.[17] The final thesis examined the role of non-load-bearing walls and transparent envelopes in French urban architecture, following the introduction of metal and glass framing in the nineteenth century. Traisnel analysed the different combinations of materials and types of architectural component he had researched – he followed both a thematic and chronological pattern. The examples he used to support his arguments referenced the key French architects and engineers who employed iron, steel and glass in their building design and construction during the nineteenth and twentieth centuries, as well as prior French thinking about these. In this way he successfully built threads of technical advance centred around the shift from traditional walls as structural and decorative support to buildings, to transparent envelopes designed to display the functional aspects of urban architecture and artfully 'capture' the air space inside buildings for aesthetic and climatic purposes.

These technological and engineering approaches to construction historiography are potentially helpful in trying to answer the question posed about determining the influence of a novel materials-system on *Belle Époque* building design in three cities and their surrounding urbanised regions – however, they first need to absorb certain aspects of architectural historiography.

Combining construction and architectural historiography

Returning to Slaton's work on the first reinforced concrete North American factories, she had referenced earlier history of science and technology doctoral research by Biggs, who had used the term 'rational factories' for SCOT artefacts with architectural aspects to them.[18] By contrast, and in 1986, a year before Bigg's doctoral research was completed, Banham had placed the same industrial buildings into an architectural typology he called 'daylight factories', which is considered further in a case study in Chapter 2.[19] Legault completed his own doctoral research a decade later on new materials and architectural modernity in France between 1889-

[17] Jean-Pierre Traisnel, 'Le Métal et Le Verre Dans l'architecture En France. Du Mur à La Façade Legère.' (Institut Français d'Urbanisme, 1997).
[18] Lindy Biggs, 'Industry's Master Machine: Factory Planning and Design in the Age of Mass Production, 1900 to 1930' (MIT, 1987); Lindy Biggs, *The Rational Factory. Architecture, Technology, and Work in America's Age of Mass Production* (Johns Hopkins University Press, 1996).
[19] Reyner Banham, *A Concrete Atlantis. US Industrial Building and European Modern Architecture.* (MIT Press, 1986).

1934.[20] He was attempting at the time, in what he perceived to be a ground-breaking approach to traditional architectural history, to provide a wider perspective on a topic that had acquired renewed historical interest in the 1990s – the story of late nineteenth-century reinforced concrete as a new combined construction material, technique and architectural system.[21] Extending beyond the thinking of Biggs, Banham, Slaton and Traisnel, Legault identified reinforced concrete and cement as more than a novel construction technology, rather it was an architectural construct shaped by a range of external factors. Legault's study, as with many others, bridged the First World War, since he was keen to make the connection across to interwar International Modernist architectural genres. His research objective was to emphasise the interplay between materials and means in architecture, such that a material (or in this thesis, materials-system) acquired "a character in which the technical and the metaphorical coalesce. My analysis may help in deciphering this 'rhetoric of materials' in the practice and interpretation of modern architecture".[22] Hence Legault's thesis also covered the technical-based origins of French rationalist architecture, echoing very much the work of Hans Straub in engineering history half a century earlier (considered further in Chapter 4), as well as contributions in the 1950s and 1960s from anglophone scholars of French architectural history such as Collins, Banham and Middleton.[23]

Another key reference work is a comprehensive doctoral thesis by Stephanie van de Voorde on the history of (reinforced) concrete in the Belgian construction industry.[24] Van de Voorde described the relevance of her historiographical approach: rather than concentrating simply on reinforced concrete as a novel construction material, she decided to focus on those Belgian actors associated with it, looking at their intentions, their

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[20] Rejean Legault, 'L'Appareil de L'Architecture Moderne: New Materials and Architectural Modernity in France, 1889-1934' (MIT, 1997).

[21] Legault had worked in collaboration with academic colleagues Jacques Gubler, Gwenaël Delhumeau and Cyrille Simonnet on interpreting the Hennebique company's vast business records acquired by the *Institut Français d'Architecture* in 1989. Delhumeau et al., *Le Béton En Répresentation. La Mémoire Photographique de l'entreprise Hennebique 1890-1930*.

[22] Legault, 'L'Appareil de L'Architecture Moderne: New Materials and Architectural Modernity in France, 1889-1934', 17–18.

[23] Hans Straub, *A History of Civil Engineering: An Outline from Ancient to Modern Times*, 1st publ ed. (Cambridge, Massachussets: MIT Press, 1964); Peter Collins, *Concrete. The Vision of a New Architecture*, 2nd ed. (McGill-Queen's University Press, 2004); Peter Collins, *Changing Ideals in Modern Architecture 1750-1950* (Faber & Faber, 1965); Reyner (Peter) Banham, 'The Theory of Modern Architecture 1907-1927' (University of London, 1958); Reyner Banham, *Theory and Design in the First Machine Age*, Paperback (1972) (Architectural Press, 1960); Robin D. Middleton, 'The Abbé de Cordemoy and the Graeco-Gothic Ideal: A Prelude to Romantic Classicism', *Journal of the Warburg and Courtauld Institutes* 25, no. 4 (1962): 278–320; Robin D. Middleton, 'The Abbe de Cordemoy and the Graeco-Gothic Ideal. Part II.', *Journal of the Warburg and Courtauld Institutes* 26, no. 1/2 (1963): 90–123.

[24] Voorde, 'Bouwen in Beton in België (1890-1975) Samenspel van Kennis, Experiment En Innovatie'.

knowledge and their achievements, so picking up aspects of the SCOT approach used by others in the history of technology. She was interested in the circles in which these actors moved, which interactions were encouraged by these networks, and how these contributed to increased knowledge and experience of the material. Van de Voorde used historical case studies to illustrate her overall concept, including one about the experimental use of different concrete systems in Belgian interwar social housing, a category which is included within the Urban Housing typology described in Chapter 6; indeed, one of the historic example buildings associated with this category is still fulfilling its original purpose in modern day Brussels (see the case study of *Habitations à Bon Marché* or HBMs in Chapter 3, particularly the HBM at 32 rue Marconi). Van de Voorde observed that the contribution of certain actors had been undervalued, even though they had an important influence on the practical and technical aspects of experimental social housing using concrete. She re-assessed the interaction between the main actors as she saw them (architects, commissioners and contractors – not specifically engineers) within a relationship between three key building history dimensions she labelled as 'design/aesthetics', 'economy/technology' and 'theory/structure'. Van de Voorde singled out the principal research focus of others on the first of these dimensions, whereas "the question of whether a project was structurally sound, theoretically possible, economically advantageous and technically feasible is much less asked."[25] In a later case study in her thesis, van de Voorde outlined the development of thin shell concrete construction in post-Second World War Belgium led by architect André Paduart, who had succeeded in combining the separate professional roles of engineer, architect and contractor, and hence in her view had permitted the three key building history dimensions to function together effectively.[26] Van de Voorde had originally hoped to answer a similar question to that posed by this researcher in this thesis, though much broader in terms of its definition and time scope: to what extent had the adoption of (reinforced) concrete as a building material influenced Belgian architecture? In her conclusion she conceded that the question would not have a straightforward answer. She therefore focused on the role of previously-unrecognised actors and their networks within the story of twentieth-century Belgian building industry.[27] In this way van de Voorde included

[25] Voorde, 583. ".. de vraag of een project structureel verantwoord, theoretisch haalbaar, economisch voordelig en technisch realiseerbaar was, wordt veel minder gesteld."
[26] Voorde, chap. 8.
[27] Voorde, 580–88.

not just the three main building professions, but also clients, concrete pre-manufacturers, housing companies, authors, research centres, associations, commentators and professional organisations.

There are many features within van der Voorde's approach that were also drawn on by Melsens in her more recent doctoral research on twentieth-century Indian architects, engineers and builders.[28] Melsens sees political and social change in a newly emancipating nation as a pivotal factor influencing a developing native architectural corps, with consequences for its professionalisation and that of the other key actors. She examines the historical context within which divergent notions of architects' professional identity developed in India, including their role in the proliferation of urban buildings, which "draws attention to the fact that the meaning of being an architect or engineer varies not only across geographies, but also that multiple notions of professional identity co-exist and compete even within a singular temporal and spatial context."[29]

Peter Collins had much earlier used his extensive understanding of historical buildings, including those designed using reinforced concrete by the Perret brothers in France, to conclude an overall strand of thinking about a logical process for architectural decision-making.[30] While this stands in contrast to the recent historiographic approaches in construction history already referenced, it does nonetheless connect to their focus on the role of key actors. The concept of an *architectural precedent* appeared in Collins' approach, linked as it seemed to be to him with the study of legal precedents. He also considered the related concept of *architectural judgement*, which had a more socially-contrived quality but clearly linked to the professional role of individual architects. Martin Bressani, once a student of Collins, lauded his former teacher's endeavour over thirty years later for providing a heuristic value to the confrontation between two disciplines that each need their followers to be able to make judgements:

> It does not seek so much to defend a thesis, as to open new perspectives for architecture which, in his opinion, is in a theoretical impasse.[31]

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[28] Melsens, 'Architect, Engineer or Builder? A History of Professional Demarcation through Practice and Discourse, Pune (India) 1930-1992'.
[29] Melsens, 409–10.
[30] Peter Collins, *Architectural Judgement* (Faber and Faber Limited, 1971).
[31] Martin Bressani, 'Vers Une Politique Du Gout: Reflexions Sur Architectural Judgement', in *Peter Collins and the Critical History of Modern Architecture*, ed. Irena Latek (lnstitut de Recherche en histoire de l'architecture (IRHA), 2002), 110.

To Collins, architecture relied on principles or concepts, which were more than a simple analogue to legal precedents. The original architectural concepts were clearly connected to the works of the ancients, most famously of all the Roman engineer-architect Vitruvius, whose three core principles for designing and constructing buildings (strength, utility and beauty) have remained with us for millennia. Regulation has an obvious legal aspect to it – otherwise it would be impossible to ensure that individuals comply with the agreed set of rules applying to their particular field. This does not necessarily mean that they fully agree with the rules, it merely implies that someone has to be the arbiter of them, and that incentives and penalties need to be enacted in order to create a compliance framework. Within the field of construction and its associated professional disciplines of architecture, engineering and contracting, such rules need to take account of specialist nuances in what might be considered a reasonable and fair way. This is why there are individuals who control the regulatory system and permit occasional exceptions with good reason, without recourse to the law courts as the final judgement on right and wrong, or even to question the extent of appropriateness to the times. As Collins put it:

> Few aspects of architectural design have a more obvious relationship with law than that which concerns the political control of urban and rural environments … few specialists in urban design have any doubt that legislative sanctions of some kind are essential if their work is to be effective.[32]

Collins subsequently made an interesting distinction between law and equity, as two separate judicial fields which gradually converged over time, irrespective of the different common law and codified systems that distinguished Anglo-Saxon from European approaches to legal matters. For him equity was the "means either of limiting the literal interpretation of laws when their strict application would be manifestly unjust, or of providing a remedy for injustice when no legal remedy could be found."[33] The obligations of those judging equity are therefore to look to their moral consciences rather than employing legal technicalities. Collins went on to interpret French architectural thinker Eugène-Emmanuel Viollet-le-Duc's (1814-1879) nineteenth century rules of architecture as following the spirit rather than the letter of law, referencing Viollet-le-Duc's compatriot Julien Guadet (1834-1908), who declared in 1904 that these rules cannot be violated easily. Collins made the following forceful statement:

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[32] Collins, *Architectural Judgement*, 64.
[33] Collins, 161.

> … it is obvious, from all that has been written on architectural theory during the last century, that insofar as architectural judgement concerns the relationship of the architect to society, its most relevant equivalent in law is to that branch of the Rights of Property which in Roman Law is termed 'Obligations'.[34]

He saw minimal social obligations of architects in the original Vitruvian principles for judging architecture, allowing a better assessment of the lowest expectations for the design of a building; importantly, Collins also permitted a higher level of optimal outcomes for society from architectural design, which he distinguished from a rose-tinted nostalgia about the past, sometimes associated with Historicism or Eclecticism:

> An architect's obligations to twentieth-century society can no longer be based on conjectural romantic interpretations of Antique or Medieval life … the fact remains that even if we could actually see these buildings in their entirety, and fully comprehend the emotions of these remote peoples for whom they were built, those emotions would have little relevance to architectural criticism today.[35]

In this way a legally-inspired reflection on architectural judgement finished with a focus on the nature of professional ideals and how architects of the 1970s needed to aspire to these, even though some of these might appear unattainable to them. This strand of thinking was echoed later by Sutcliffe, who specifically referenced *Belle Époque* Eclecticism and it most artistically creative genre, which is considered more fully in Chapter 5:

> The architectural debate over *Art Nouveau* and other, less alien styles took place within a broader context which influenced much artistic discussion: the idea of a single aesthetic system which would be guaranteed to produce beauty. This was of course the claim of the classicists, but the new system was seen as less a matter of rule and proportions than one of individual expression fired by a common spirit.[36]

Addressing the knowledge gap

The historiographic review began by highlighting the technological and engineering aspects of construction historiography, with a focus on relevant SCOT doctoral research by Slaton on early North American reinforced

[34] Collins, 162.
[35] Collins, 166.
[36] Anthony Sutcliffe, *Paris: An Architectural History.* (Yale University Press, 1993), 117.

concrete factories and Deuten on historic innovation in reinforced concrete and cement systems. Addis's models for the engineering design process and associated Design Revolutions were introduced and adapted, as well as referencing research by Traisnel on the development of metal and glass walls in historic French buildings. While Addis wanted his description of those who have been responsible for shifting communal Design Procedures in construction over time to be inclusive, inevitably his argument veered towards his familiar ground of the highly technical and specialised roles of civil and structural engineers. To this extent, a modern civil engineering definition of structural (building) design is helpful at this stage:

> The creation of a structure starting with an idea and vision of what may be required and finishing with the physical reality of a structure. In the past this was a term used only to refer to the proportioning of structural members to carry loads - that is now quite inadequate as structural engineers need to be involved in the whole concept from the start, working within the design team.[37]

But the Design Procedure and Design Revolutions models also require an additional layer that encompasses *all* those who were engaged in the building design *and* construction process, including not just architects and engineers, but also contractors. To some extent Andrew Saint laid the groundwork for this in his examination of the historic 'sibling rivalry' between the key construction design professionals, discussed in Chapter 4 with a proposal to extend the term to 'sibling rivalry *and cooperation*'.[38] Such an additional layer needs to capture structural requirements as direct responses to a building commissioner's needs – for example, as seen in an architect's or engineer's technical building design using their full expressive freedoms to provide a finished structure within the normality of a localised context. Contractors have also been encouraged by project and operations managers to seek cost-efficient, low-maintenance construction approaches, sometimes being pushed to cut corners on aesthetics, longevity and safety, despite any precautionary regulatory measures that may be in place. This all implies the need for building commissioners, architects, engineers and contractors,

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[37] David Blockley, *The New Penguin Dictionary of Civil Engineering* (Penguin, 2005), 452–53.
[38] Andrew Saint, 'Architect and Engineer: A Study in Construction History', *Construction History* 21 (2005): 21–30; Andrew Saint, *Architect and Engineer: A Study in Sibling Rivalry* (Yale University Press, 2008).

perhaps other actors as well, to rely on someone to take on a mediating role when it comes to differences of opinion and levels of risk.[39]

The historiographic review noted separate but parallel research by Biggs (a historian of science and technology) and Banham (an architectural historian) in the 1980s on under-studied early North American 'rational' or 'daylight' factories, prior to Slaton's technical analysis of the typology as it developed after the First World War. As also seen, two later doctoral theses have each attempted to combine technological and architectural historiographical approaches to analyses of reinforced concrete, in what could be termed exercises in closing knowledge gaps: the first by Legault (1997) focused on the early history of reinforced concrete and cement in French building design, so not solely *technical* design and with less study of the construction process compared to this thesis; and the second by van de Voorde (2011) examined the history of concrete in Belgian building design and construction over a much longer span than Legault's or this thesis. Both the theses by Legault and van de Voorde covered the period of the *Belle Époque* and used different conceptual approaches to describe the relationship between the new systems and associated aesthetic design outcomes. The examination in this thesis of the influence of innovative reinforced concrete and cement systems on *Belle Époque* building design is a restatement of Legault's original architectural construct, bringing together as it does the 'technical and the metaphorical', but employing a greater technological perspective to it. Within this approach, the term 'novel materials-system' is used rather than Picon's more transitory 'system-into-material'; in this way the term describes a unified technical concept for a number of constituent materials that to this day still express their separate physical properties, as it happens, often in a mutually compatible manner. The novel materials-system is then placed within an adaption of Addis's model of engineering design processes and paradigms, so that it is more closely associated with two separate but related stages of a metallic building design revolution; these saw a transition from the monumental employment of iron and steel in and near Paris (1864-1889), to the use of reinforced concrete and cement systems in *Belle Époque* non-monumental urban buildings in and near Paris, Lille and Brussels (1892-1914), all of which is fully described in

[39] The historical and modern tension between innovative technical design and its satisfactory application in building construction parallels a biological explanation for risk-taking; it is seen as a by-product of the conflict between paternal and maternal genes, each trying to improve their own chances of reproduction. The biological science is described by Isles, Winstanley, and Humby. Anthony R. Isles, Catharine A. Winstanley, and Trevor Humby, 'Risk Taking and Impulsive Behaviour: Fundamental Discoveries, Theoretical Perspectives and Clinical Implications', *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* (NLM (Medline), February 2019).

Chapter 5. Neither thesis by Legault nor van de Voorde looked at a 'novel materials-system' as it is defined in this thesis, nor did they adapt Addis' models into stages of a metallic design revolution, as is also done in this thesis; neither did they employ Saint's 'sibling rivalry' approach, nor the suggested adjustment in this thesis to 'sibling rivalry and cooperation' that is more inclusive of the role of contractors – admittedly van de Voorde did include a vast range of actors within construction, as did Melsens afterwards with her multiple notions of professional identity.

Peter Collins' much earlier study of architectural judgement brought the historiographic review to an end, by introducing the historic role of legally-derived principles and precedents and their relationship with decision-making in technical and aesthetic design, connecting this to the shared societal obligations of architects (and by implication other construction professionals) over time. Sutcliffe subsequently made the link from Collins to *Belle Époque* creative expression, particularly radical *Art Nouveau* approaches, that was attempting to unify architectural aestheticism across a landscape of Eclecticism. There is a direct connection from Sutcliffe to a recent doctoral thesis by Gillet (2020) that examined the employment of tiles in the facades of five *Art Nouveau immeubles* completed in Paris before 1914 using reinforced concrete skeletons; two of these buildings are used in in Chapter 5 of this thesis as historic examples in a case study of Parisian *immeubles* with decorative ceramic facade cladding.[40] While Gillet's research interest was focused on the use of ceramic tiles as a cladding material, he did reference prior works that had attempted to describe the tectonic relationship between the innovative reinforced concrete or cement framing that was hidden behind the tiles, and *Belle Époque* architecture.[41] This thesis is a step beyond Gillet, with a remit that is materially, geographically and structurally wider, and with a greater focus on filling the knowledge gap about the influence of the novel materials-system on technical aspects of building design in the period.

[40] Valentin Gillet, 'Conception et Confection. Une Histoire Matérielle Du Revêtement Céramique Des Immeubles Parisiens (1900-1914)' (ETH Zurich, 2020).
[41] Gillet. See particularly pp. 29-32.

Research Methodology

It became clear from producing the historiographic framework and through analysis of available secondary and primary evidence that finding an answer to the question, 'What was the influence of novel reinforced concrete and cement systems on non-monumental, urban building design in and near three *Belle Époque* cities?', would require a suitable tool to substantiate and describe any historical causation. The researcher turned to 'process tracing' literature, which revealed the potential for employing a historical mechanism.

Process tracing

In 2014 a group of international human and social scientists published a compendium of papers about 'process tracing', a relatively new methodological approach to their own disciplines. Two of the groups described process tracing as "the employment of evidence from a case to infer its causal explanations".[42] They defined a case as a socially-contrived instance of a class of events. Mahoney described in a related paper of the same year process tracing practice and a method for creating a mechanism (a factor that intervenes between a cause and outcome) for historical causation. This required that the historical analyst had good knowledge of the history of the case and relevant pre-existing theories, as well as a good ability to undertake sound logical reasoning by combining facts about the case with more general knowledge.[43] This doctoral researcher has: a) collected both contextual and direct evidence about historical buildings defined by the key parameter that they used a novel materials-system in a specific period and geography; b) operated as a logical historian who has read broadly around his topic; and c) used a) and b) to describe a historical mechanism indicating a relationship between cause and outcome for this particular doctoral research.

Mahoney went on to describe how 'hoop' tests were used to confirm the significance of either unique events, or historical mechanisms as a combination of inter-related individual events. The outcomes of these 'hoop' tests might potentially contribute to the verification or negation of an existing hypothesis. But this depended on the difficulty of the 'hoop' tests, as they required observations that were "rare, abnormal, or unusual" to

[42] Andrew Bennett and Jeffrey T. Checkel, 'Process Tracing From Philosophical Roots to Best Practices', in *Process Tracing: From Metaphor to Analytic Tool*, ed. Colin Elman, John Gerring, and James Mahoney (Cambridge University Press, 2015), 4.

[43] James Mahoney, 'Process Tracing and Historical Explanation', *Security Studies* 24, no. 2 (April 2015): 202, 206.

the case being studied. Too easy 'hoop' tests made use of observations that were "ordinary, common, or expected."[44] In this way, while failing a 'hoop' test negated a hypothesis, passing a 'hoop' test did not necessarily confirm the hypothesis. According to Mahoney, 'smoking gun' tests are less definitive than 'hoop' tests and work in the opposite logical direction i.e. inductive versus deductive reasoning. An analogy would be to compare 'smoking gun' tests with the use of counterfactuals to explain the causes and outcomes of historical cases, where for example alternative explanations from the same or a different time period can convey 'what if' scenarios. Research by Levy illustrates historical process tracing through a major 'smoking gun' test: an oft-cited cause of the First World War was the assassination in 1914 in Sarajevo of the Austrian Archduke Franz Ferdinand by a Serbian extremist.[45] The evidence for the significance of the single, momentous event was tested by Levy to see how it impacted on the subsequent declaration of war by Austria on neighbouring Serbia, and in turn to the next events in a chain or historical mechanism that led to a European-wide conflict.

The same logic can be applied to other historical scenarios to identify a historical mechanism and contribute towards the beginnings of a possible new approach to research in a field. Hence, this doctoral research has applied more or less difficult 'hoop' and 'smoking gun' tests to contextual, direct and indirect observations about a range of potential historic example buildings. The observations were treated as being 'typical' rather than 'atypical' and multiple approaches were used to categorizing differing and shared features across these buildings within different technical, societal and building design contexts and, ultimately, illustrated through six case studies and categorised into two typologies, 'Urban Industrial' and 'Urban Housing'.

Research boundaries

Both the historiographic review and the process tracing tools suggested the potential value of an inclusive approach, capturing both cross-disciplinary and discipline-specific issues within the history of construction, including historiographical perspectives from technology, engineering and architecture. A key objective was to produce through technical, societal and building design contexts for, as well as actual evidence of, historic example buildings, a suitable historical mechanism to help describe a broader causal effect. The premise for

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[44] Mahoney, 207–8.
[45] Jack S. Levy, 'Preferences, Constraints, and Choices in July 1914', *International Security* 15, no. 3 (1991): 151–86.

this historical mechanism is also derived from Addis's Design Procedures and Revolutions models, which lead to the description of the second stage of a metallic building design revolution in Chapter 5 – and immediately implies there was a first stage, also described. However, clear boundaries needed to be set within the research and these have limited, for good reason, how much might be covered.

In terms of the geographical coverage of the research, Paris, Lille (now known as *Métropole Européenne de Lille* which includes the former industrial cities of Roubaix and Tourcoing) and Brussels, were cities within a swathe of northern France and southern Belgium connected by francophone language and culture (Figure 0.4).

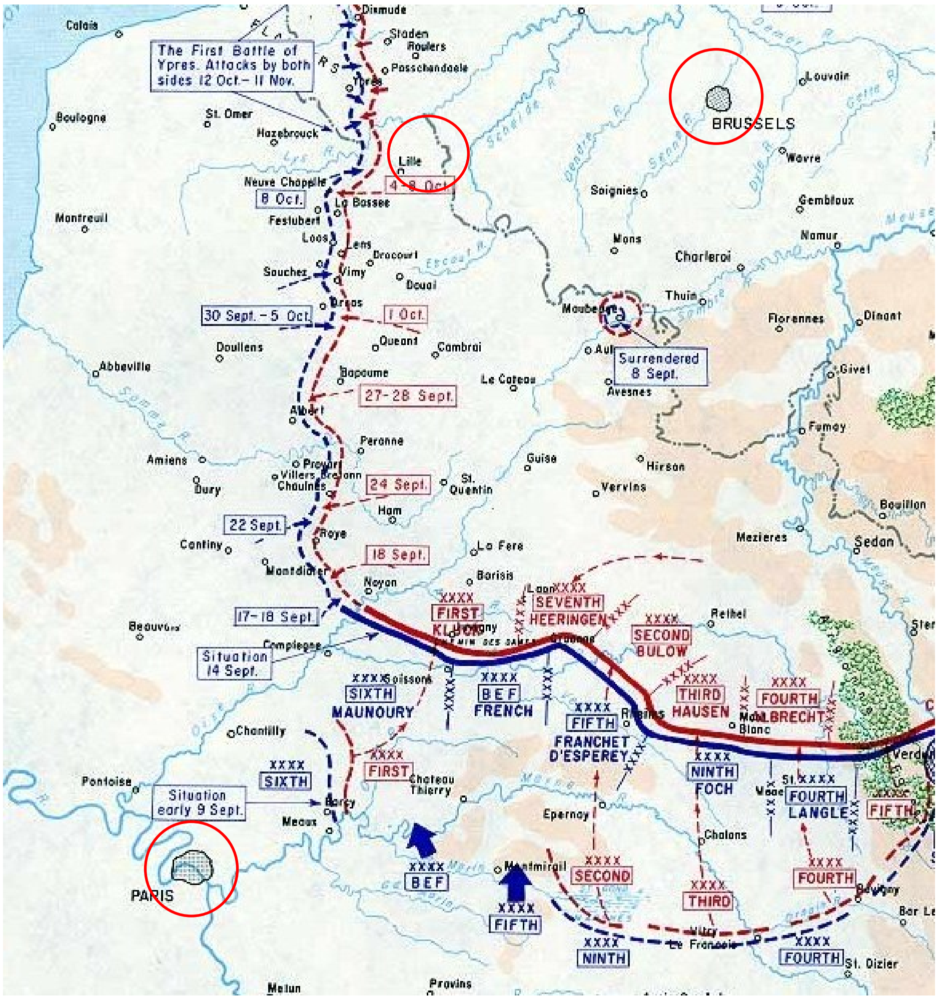

Figure 0.4. Map showing the geography of the thesis, with Paris, Lille and Brussels all circled in red. The extensive Western Front of 1914 captures the dramatic end of the Belle Époque.
(Creative Commons. The History Department of the US Military Academy West Point)

They had many non-monumental, urban buildings during the *Belle Époque*, including what were once, and in some cases still are residential blocks, factories, warehouses, banks and communal archives. The three cities and their environs map well onto the initial sales territory of François Hennebique's novel *béton armé* system developed and extended during the *Belle Époque* – the inventor had been born in a village near Arras in the *Département du Pas de Calais*, of which Lille was the administrative capital, but his first operational headquarters were in Brussels and he moved them subsequently to Paris in the 1890s, where they became a global design office for a major new reinforced concrete system.

The focus of the thesis remains on the evidence from and context for historic example buildings that illustrated well the use of new reinforced concrete and cement systems in urban building design. Since it was not at first considered acceptable to display the novel materials-system overtly on a typical urban street, given its plain engineering and industrial connotations, the research parameters minimised examples of monumental urban architecture completed during the *Belle Époque*. Iron and steel skeleton buildings were filtered out during the selection process for the historic example buildings in the case studies, though some are still used to describe the broader context of building design during the *Belle Époque* in Chapter 5. The thesis therefore has three subsidiary research questions, which individually set the framework for each of the three sections on technical, societal and building design context:

1. Section 1 on the technical context: 'What were the key technical demands of the new reinforced concrete and cement systems and how did these manifest themselves within building design and construction during the period?'
2. Section 2 on the societal context: 'How did the employment of new reinforced concrete and cement systems reflect societal expectations and in what ways did these manifest themselves within building design and construction during the period?'
3. Section 3 on the building design context: 'Which factors shaped *Belle Époque* urban building design and how did they interact with key technical demands and societal expectations for the novel materials-system?'

The answers to these three questions (of which those to 1 and 2 are represented through schematics with key information blocks and associated details in their respective section summaries) collectively contribute to formulation of the historical mechanism designed to help answer the core research question, 'What was the influence of novel reinforced concrete and cement systems on non-monumental, urban building design in and near three *Belle Époque* cities?' The core research question is answered in the Conclusion to the thesis.

The choice of the final thirteen historic example buildings in the six case studies, and the allocation of specific examples to specific cases studies, depended on the wider context of each section of the thesis in which they sat. A case study for the purposes of this thesis is therefore not a study of a single exemplary building, the approach taken by Gillet in his thesis, rather a vehicle or lens by which one or more historic examples are used to illustrate a key aspect within the context. These examples aren't evenly spread between case studies, but instead range from single historic buildings to a maximum of four buildings in one case study. In Section 1 there are two cases studies comprising three example buildings that illustrate well key aspects of the technical context for the use of the novel materials-system. The first case study illustrates well structural specifications, which are a component of early industrial standards for the novel materials-system (see Chapter 1). The second case study illustrates well a key structural requirement of greater daylight admission into buildings that was sought particularly by aspiring owners of 'daylight factories', and for which there are two historic examples (see Chapter 2). In Section 2 there are a further two case studies comprising four example buildings that illustrate well aspects of the societal context for the use of the novel materials-system. The first case study illustrates well social housing through three historic examples that used the novel materials-system, not commonplace before 1914 (see Chapter 3). The second case study illustrates well the relationship between use of the novel materials-system and the gradual easing of post-Haussmannian street regulations in *Belle Époque* Paris, through the example of a unique *immeuble* designed and built for François Hennebique using his *béton armé* system (see Chapter 4). Finally, in Section 3 there are two further case studies comprising six example buildings that illustrate well aspects of the building design context for the use of the novel materials-system. The first case study illustrates well the use of novel street decor for two historic buildings with an *Art Nouveau* facade hiding a reinforced concrete or cement skeleton (see Chapter 5). The second case study illustrates well new approaches to urban design in four commercial and administrative historic buildings that employed the novel materials-system (see Chapter 5).

The key initial task was to produce and then filter from a list of more than fifty *Belle Époque* urban buildings in or near Paris, Lille and Brussels for which (combinations of) iron, steel, cement and concrete were used in their construction (see Appendices). Buildings were added or removed from the list according to the clarity and relevance of any evidence about their use of iron, steel and reinforce concrete or cement. Chapter 6 divides twelve of the final thirteen historic example buildings used in the case studies into two groups of six that each form typologies called Urban Industrial and Urban Housing. Each typology is defined and then compared with the other; in this way contributing towards the production of the historical mechanism that is fully described subsequently in the chapter. A number of the other historic example buildings in the larger list were referenced within the text and the historical mechanism was used on one of them, the immeuble at 25b rue Benjamin Franklin in Paris by the Perret brothers (1904).

The influence of a novel materials-system on historical building design is therefore a key focus of the research. More precisely, and here the connection with Addis's 'Design Procedure' model is important, the things being assessed for how much they were influenced were the *technically oriented* aspects of the building design process and the constraining environment, all set within wider contexts. There is more in the subsequent summaries of Sections 1 and 2, and specifically in Chapter 6 about what this means in terms of the details of the historical mechanism – but for the purpose here of describing the research boundaries, the use of a systematised technical design process for these historic example buildings was bound to include a more subjective appreciation of the new materials and how they contributed to the shape,form and decorative aspects of a structure – the use of the term 'architectonics' to describe this relationship is to my mind insufficient, even though it has some facets which are helpful to the discussion.[46]

Evidence sources

Specialist databases and catalogues were initially suggested by my supervisors, Kent and Lille University librarians and other researchers, for which their assistance was greatly appreciated. Primary sources have included contemporaneous specialist publications freely accessible online and/or physically at key national libraries in Paris and Brussels. While the researcher was based in the UK during Year 1 which coincided with the ongoing COVID pandemic, if there was no electronic text available through specialist catalogues, and other generalist catalogues could not provide an easily accessible copy, then this ended with a request to the British Library and the RIBA library (once lockdown rules had been eased) to view onsite a print copy or restricted e-version. If a part of a document or a whole text was found to be downloadable or could be scanned or photographed electronically, a PDF version of the text was saved and its contents organised, searched and

[46] Maulden, who was also not keen on using the term 'architectonics' in his thesis on tectonics in architecture, defined the latter as "the narrative capacity of architecture; an architecture inseparable from construction. It is the modelling of the physical things of a building — the structure, the enclosure, materials, organization — bringing it into the meta-physical world." Robert Maulden, 'Tectonics in Architecture' (MIT, 1986), 81.

annotated using Adobe Acrobat. Year 2 of the project saw me able to access directly while based in Lille, French and Belgian libraries and national and local physical repositories of original historic documents, allowing for continuing COVID-19 visit restrictions. Visits were made to the sites of many historic buildings that still existed, though entry to most was restricted. See the Bibliography for full details of archival sources, as well as primary and secondary literature, and the Appendices for tables of additional data and a list of example historic buildings considered for further research and analysis in the thesis.

Section 1. The technical context of *Belle Époque* construction using the novel materials-system

Section introduction

Section 1 describes the technical context of *Belle Époque* construction using a novel materials-system, setting the scene across two connected chapters. The section contains two case studies comprising three historic example buildings that, together with the remaining text, answer the subsidiary research question: ‘What were the key technical demands of the new reinforced concrete and cement systems and how did these manifest themselves within building design and construction during the period?’

Chapter 1 covers the emergence of industry standards for engineering, as well as innovation and construction industry design standards more generally. The three key components of early industrial standards for the novel materials-system are then examined: a) industrial patents for new reinforced concrete and cement systems; b) structural specifications, with a case study of a historic building illustrating these well; and c) technical guidance. The chapter finishes with an analysis of the influence of voluntary French national guidance published in 1906 on the novel materials-system.

Chapter 2 examines the economics of building, as well as four key structural requirements associated with specific commissioner needs for new *Belle Époque* buildings that employed novel reinforced concrete and cement systems: fire resistance, structural efficiency, daylight admission and street decor. The third of these structural requirements connects to a ‘daylight factory’ architectural typology, derived from pre-First World War North American reinforced concrete factories with an associated interwar International Modernist trope; this is exemplified in a case study of two historic example buildings from the *Belle Époque* that fit the architectural typology well, indeed the first of them precedes it by about five years.

The section concludes with a simplified schematic connecting key information blocks within the two chapters in the section, as well as indicating the most significant details linked to them, in the form of answer to the subsidiary research question.

Chapter 1: Early industrial standards for innovative construction systems

This opening chapter considers the historical development and significance of voluntary standards for engineering, where the shared codification of knowledge still acts as a stabilising process in what would otherwise be a highly disparate landscape. Attention is then paid to the key relationship between innovation and industrial (design) standards for construction. Research by a modern expert describes in detail the purpose of construction industry *design* standards. Three types of role are identified for these: a) meeting the high-level *objectives* of standardisation; b) providing quality *content* for a 'good' construction industry design standard; and c) aiding with the actual *design* of the planned work. The chapter outlines three key components of early industrial standards for novel reinforced concrete and cement systems: industrial patents, structural specifications and technical guidance. The novel reinforced concrete and cement systems featured in the historic example buildings are then described. The chapter examines the legal aspects of the competitive environment that François Hennebique and Armand Considère, as French inventors of the *béton armé* and *béton fretté* systems, had created within a construction industry that began to adopt the novel materials-system. The chapter then considers structural specifications for the design and construction of urban buildings, with a case study of an industrial building that was one of the first to use the *béton armé* system. Technical guidance for the novel materials-system is described, together with an examination of voluntary French national guidance on reinforce concrete and cement systems for state-commissioned construction projects, produced in 1906.

1a. The emergence of industrial standards for engineering

Yates and Murphy have examined the history of engineering standards in a comprehensive work, in which they place the historical role of these types of voluntary technical standards within the mainstream of the world's developing economies over time.[47] They observe that these engineering standards have shaped industrial development by fixing the technological platforms on which further innovation occur:

[47] JoAnne Yates and Craig N. Murphy, *Engineering Rules. Global Standard Setting since 1880* (John Hopkins University Press, 2019).

> Without such standards, most of what we buy would be more difficult to produce, and conflicts between merchants and customers would likely be more intense … this kind of private standardization has come to provide a critical infrastructure for the global economy.[48]

But applying technical standards to the real world takes time; Yates and Murphy observe that France had to wait until 1840 to fully adopt the physical standards of the metric system introduced in 1799 by Napoléon Bonaparte. Hence they single out a consensus-based approach, involving voluntary industrial participation, as being essential to the long-term adoption of engineering industry standards in the twentieth century. According to Sir John Wolfe Barry, a former President of the Institution of Civil Engineers (ICE) and the recognised 'father' of British Standards, the famous lexicographer Dr Johnson had defined a standard as far back as 1785 as "that which is of undoubted authority; that which is the test of other things of the same kind"; while Webster had refined this in 1853 to "that which is established as a rule or model by the authority of public opinion or by respectable opinions, or by custom or general consent."[49] Over time engineering-based and other voluntary national standards, including those set by the Association Française de Normalisation (AFNOR) established in 1926, and in the subsequent year the precursor to the current Bureau de Normalisation (NBN) in Belgium, were integrated into a worldwide set overseen by the International Standards Organisation (ISO) after the Second World War. All these national and international standards bodies have worked and continue to collaborate closely with governmental physical laboratories, originally set up in the nineteenth century to standardise scientific and engineering measurements for the benefit of military and industrial needs.

Sir John Wolfe Barry had reinforced the merits of early voluntary standardisation in engineering, highlighting the campaign by Sir Joseph Whitworth begun in 1841 to adopt his innovative screw thread as a norm for all other similar components – which had failed. Responding favourably in 1917 to Wolfe Barry's speech was the then British wartime Minister for Labour, John Hodge MP, who singled out his own pre-war experience working in a rolling-mill, producing a plethora of non-standardised iron and steel sections and parts for demanding engineers and 'faddish' architects, as he referred to them somewhat dismissively.[50] However, it

[48] Yates and Murphy, 2.
[49] John Wolfe Barry, 'The Standardization of Engineering Materials, and Its Influence on the Prosperity of the Country. The James Forrest Lecture 1917' (ICE, 1917), 332.
[50] Barry, 349.

would still take time for the role of industrial standards to be fully recognised by every part of British industry or indeed other government ministers, with the devastation of two World Wars and an intermediate global economic depression providing useful impetus.[51] Schmidt and Werle had, prior to Yates and Murphy, examined the historical standardisation of processes and interactions for the global telecommunications industry.[52] They generalised the role that engineering industry standards played in codifying knowledge elements used by people and organisations. Schmidt and Werle's work has proved helpful for this researcher by providing a different discussion of the relationship between technical knowledge and technical standards (italics added for emphasis):

> *… standards are often regarded as specific codified knowledge elements with high normative significance* … they result – precisely because of their presumed stabilizing effects – from contentious processes of standardization, involving actors from different social groups holding diverging values and interests and different knowledge bases.[53]

1b. Innovation and construction design standards

Lambert and Temple fully analysed the relationship over time between standards and innovation, producing the complex diagram shown in Figure 1.1 below which reflects the many different science and technology networks that have sprung up since the early twentieth century.[54]

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[51] As McWilliam noted in his thorough research on the evolution of British Standards, the Indian part of the vast British Empire was much more receptive to new steel industry standards. Perhaps ironically, more than a century later the Indian conglomerate Tata Steel acquired British Steel. Robert C. McWilliam, 'The Evolution of British Standards' (University of Reading, 2002); Robert C. McWilliam, 'The First British Standards: Specifications and Tests Published by the Engineering Standards Committee, 1903-18', *Transactions of the Newcomen Society* 75 (2005): 261–87.

[52] Susanne K. Schmidt and Raymund Werle, *Coordinating Technology. Studies in the International Standardization of Telecommunications* (MIT Press, 1998).

[53] Schmidt and Werle, 41.

[54] Ray Lambert and Paul Temple, 'The Relationship between Standards, Standards Development and Intellectual Property' (London: BSI, 2015).

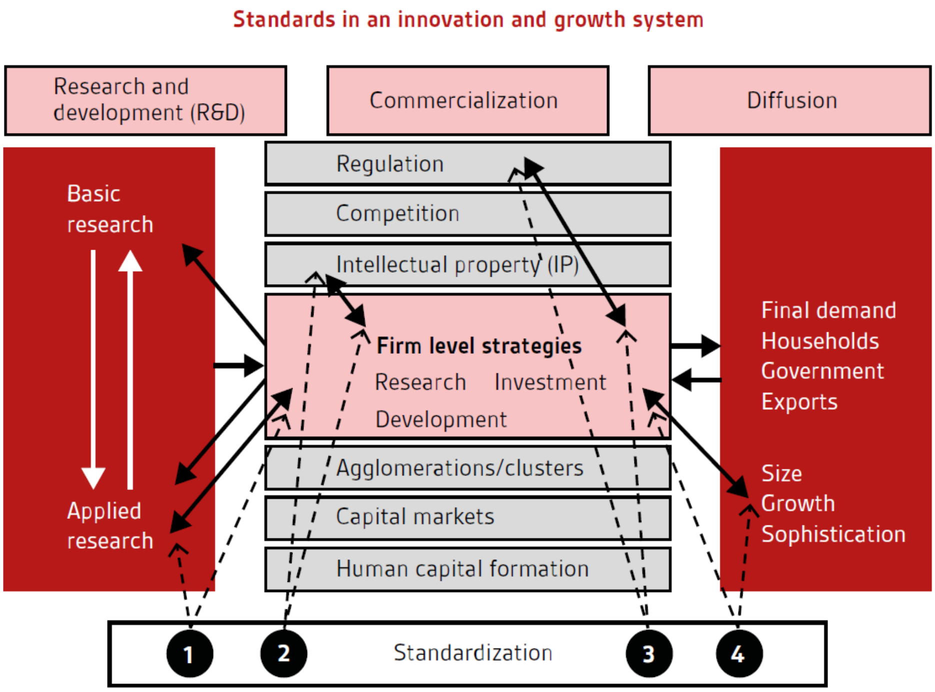

Figure 1.1: Diagram of standards in an innovation and growth system. (Lambert and Temple, 2015, p.19. Permission to reproduce extracts from British Standards is granted by BSI. British Standards can be obtained in PDF or hard copy formats from BSI Knowledge: https://knowledge.bsigroup.com or by contacting BSI Customer Services for hardcopies only: Tel: +44 (0)20 8996 9001, Email: cservices@bsigroup.com.)

Interestingly, the very busy diagram includes 'intellectual property' as a product of creative thinking encapsulated in patents and copyright, specific components of a now intricate system of technical standards and innovation interrelationships. The United Kingdom had produced voluntary industrial standards for new building materials which were published and subsequently (at least partially) adopted by the construction industry before the First World War. This was done firstly in 1903 (for steel), and then in 1904 (for Portland Cement), under the voluntary aegis of the 'Engineering Standards Committee' (ESC) formed by key professional and trade bodies; ESC was a precursor to the still extant British Standards Institution (BSI) and was established in 1901 under the leadership of the ICE to help serve the supply needs of the global British Empire.[55]

David Yeomans examined in considerable detail the key innovative materials and systems of the British construction industry from 1900 onwards, with the accompanying tensions that arose, giving him the impression that new scientific understanding had been forced upon that industry as an unplanned reaction to specific extraneous factors:

[55] McWilliam, 'The First British Standards: Specifications and Tests Published by the Engineering Standards Committee, 1903-18', 269, 274.

> This may have been because of failures of various methods of construction, because the industry was seen to be failing adequately to serve social needs, or when changes within the industry demonstrated that existing craft practices were inadequate.[56]

Specifically on voluntary national industrial standards for the construction industry, Yeomans chronicles key developments such as the transfer of the 1942 wartime 'Codes of Practice for Buildings' to BSI and hence their incorporation into British Standards for construction. Civil engineer Mariapia Angelino undertook practice-based doctoral research on the complexity of the current generation of construction industry standards, with a focus within these on the building design process, though with no specific reference to Addis' Design Procedure approach outlined earlier in the historiographic review.[57] Angelino's methodology echoes aspects of research by Deuten also referenced earlier – using a similar, but more finessed SCOT methodological approach to that of Schmidt and Werle for engineering industry standards as a means of codifying technical knowledge, Deuten had shown that the development of reinforced cement and concrete systems was an example of the transition from a localised to a cosmopolitan (e.g. global) technical knowledge system; this was achieved through more and more explicit descriptions of patents and associated technical information.[58] While Schmidt and Werle and then Deuten did not specifically single out the *design process* as a key aspect of a developing technical knowledge system, by contrast, Angelino did focus on industrial design standards for construction. She first indicated that there are six historical purposes for construction industry standards: control of the built environment by public authorities; safety; cost-efficiencies; consistency; allowing shared stakeholder communication; and competitiveness.[59] Angelino then provided a helpful diagram of a knowledge encoding and decoding process for creating new construction industry design standards which connects back to Schmidt and Werle's earlier approach (Figure 1.2).

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[56] David Yeomans, *Construction Since 1900: Materials* (BT Batsford Ltd, 1997), 14.
[57] Angelino, 'Developing Better Design Standards for the Construction Industry'.
[58] Deuten, 'Cosmopolitanising Technologies : A Study of Four Emerging Technological Regimes', chap. 4.
[59] Angelino, 'Developing Better Design Standards for the Construction Industry', 78–80.

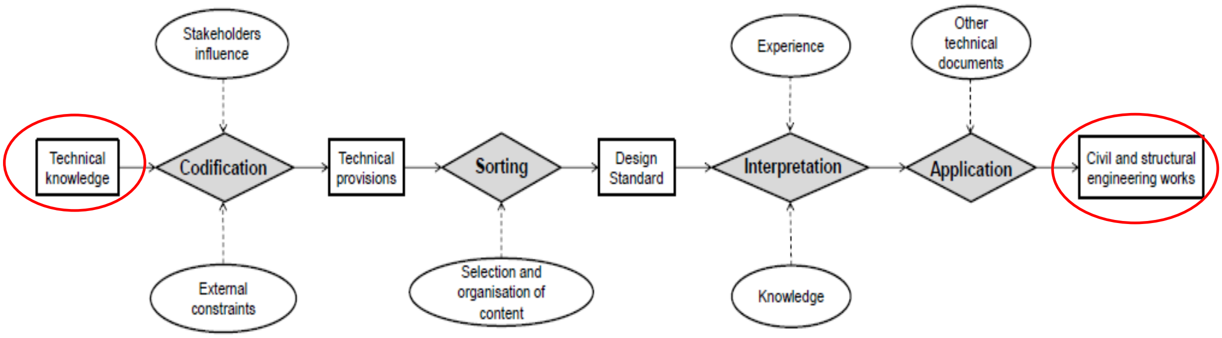

Figure 1.2: Flow process for the codification of construction industry design standards. (Angelino, 2019, p.112, Creative Commons Attribution - NonCommercial-No Derivatives 4.0 International Public License)

Angelino's flow process starts with a block of new technical knowledge within the construction industry, highlighted by me on the far left of the diagram; and then it ends with new civil and structural engineering works, highlighted again by me on the far right of the diagram. Each stage of the knowledge codification and application process from left to right has inputs from a range of key stakeholders, which build on the existing knowledge base, while the whole construction industry design standard process also reacts to external constraints, as does Addis's Design Procedure of which it appears she was not aware. The output at the mid-point of the process is a construction industry design standard, highlighted in the centre of the diagram, which then needs to be fully interpreted and applied in order to produce a 'standard' structure that reflects, satisfactorily, the new technical requirements for the innovation. Angelino goes on to show that there are three key historical purposes for construction industry *design* standards, that condense the original six purposes for more general industrial standards: enabling the adequacy of construction design to be verified; supporting both common and innovative design solutions; and managing risk and uncertainty in construction.[60] This produces a matrix of modern-day roles for construction industry design standards categorised by the following three key features:

a) those related to high level *objectives* of standardisation e.g. controlling the built environment and enabling the adequacy of building design to be verified;

b) those related to the *content* of a design standard e.g. codifying technical knowledge in a user-orientated fashion and ensuring consistency of design approaches;

[60] Angelino, 88–89.

c) those related to the actual *design* of the constructed product e.g. supporting the design of a desirable, safe, cost-effective and (environmentally) sustainable civil and structural engineering work.[61]

Modern construction designers believe that there is value in focusing on the standardised use of industry-prevalent materials (or materials-systems) rather than simply on individual structures. Hence, the main benefit to them of structure-type design codes is the availability of all information they need for a specific structure in a single document. But equally there is a downside to this:

> On the other hand, [it was argued by them that] the behaviour of a material does not change from application to application and [that] organisation according to structure type [as opposed to material type] leads to the duplication of information and possibly inconsistent terminology and design philosophy.[62]

This last point is very much set in the context of the modern era with its plethora of step-shift and incremental product innovations, presenting all kinds of complexity to both the producers and end users within the construction industry.

Returning to the historical context of technical innovation within the construction industry, Deuten emphasised that knowledge was transferred between individuals and between organisations in the industry, often in parallel, though this might be at different rates and with varying levels of detail. The image of the solitary construction systems inventor would gradually change over time as professional technical networks expanded and technical education about novel materials-systems improved and became more accessible and formalised. In the case study Deuten used of reinforced concrete, this had begun as a "deeply mysterious" local nineteenth-century technology, without sufficient collective technical knowledge:

> Indeed, patentees resisted to reveal knowledge of their proprietary systems. In the twentieth century, reinforced concrete became a cosmopolitan technology with an institutionalised knowledge base, a local-cosmopolitan division of labour, and an elaborate infrastructure for circulation and aggregation.[63]

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[61] Angelino, 103–5.
[62] Angelino, 111.
[63] Deuten, 'Cosmopolitanising Technologies : A Study of Four Emerging Technological Regimes', 89.

Hence François Hennebique was proud to proclaim in 1899 to his organisational congress and through the readership in his communications network, that he and his family had formalised their intellectual ownership of the *béton armé* system, even though he had initially questioned the legal value of patents in protecting his rights as an inventor:

> I researched the background to the reinforced cement issue; having ensured that no prior invention destroyed the value of my discovery, I lodged my patents which are intended to protect my [intellectual] property. By the way, such property is the most poorly protected in existence. The law under which patents are granted to us seems to be much more a trap to bring down and destroy industrial property than a *palladium* intended to protect it. Be that as it may, good or bad, I proposed to leave my son in charge of exploiting my previous [patents] and I decided to continue to manage my construction sites.[64]

As we will see later in this chapter, seven years after this speech, when the time came for Armand Considère to earn fees from his 1901 patent for *béton fretté* system after relinquishing state service in 1906, Hennebique was fighting a rear-guard action against a flourishing of competing reinforced concrete and cement systems, often taken forward by the very same people who had initially collaborated with him. It was in Hennebique's interest to turn from poacher into gamekeeper: the financial returns to his centralised design studio were being threatened as his patents expired and his former professional clients decided they could now operate at an equal or better level of expertise without losing a cut of their revenues to an outsider. There was a risk that they might be proved wrong, but they were more prepared to take it than they had been a decade earlier; the wider issue of professional risk-taking associated with the novel materials-system is considered in Chapter 6, but next we move on to the patented reinforced concrete and cement systems themselves.

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[64] François Hennebique, 'Troisième Congrès Du Béton de Ciment Armé. Séance Du Mardi Soir 24 Janvier 1899.', *Le Béton Armé* 1, no. 11 (April 1899): 2–3. « Je fis des recherches sur les antécédents de la question du Ciment armé; m'étant assuré qu'aucune antériorité d'invention ne détruisait la valeur de ma découverte, je pris mes brevets qui sont sensés des titres de protection de propriété. Soit dit en passant que cette propriété est bien la plus mal assurée qui existe. La loi en vertu de laquelle on nous délivre les brevets, parait être beaucoup plus un traquenard pour faire tomber et détruire la propriété industrielle qu'un palladium destiné à la protéger. Quoiqu'il en soit, bons ou mauvais, je me proposais de laisser mon fils à la tète de cette exploitation de mes précèdes et je pensais continuer à diriger mes chantiers de construction. »

1c. The novel reinforced concrete and cement systems

Early industrial standards for the novel materials-system were linked to the revolutionary transition of Addis's community of 'normal' to 'new normal' Design Procedure, described in the historiographic review and which will be developed further in Chapter 5. Architects, engineers and contractors had started to use a metal and cement or concrete combination to replace traditional timber, bricks and masonry, as well as the separate application of cement or concrete to iron or steel internal members; with various, oft-claimed 'fire-proof' features, in effect meaning an improved fire resistance of buildings. Initially, all types of system included iron girders or rebars, but over time the iron was replaced by thinner and stronger steel elements; by the first decade of the twentieth century it appears that steel predominated in Belgian (due to its vibrant steel industry) and probably in neighbouring France as well.[65] Reinforced concrete and cement systems both required liquid cement, a fluid, lithic material produced by combining a mineral powder with water. It was invented by the Romans using water-resistant Neapolitan volcanic ash (*Pozzolana*) and then rediscovered and developed centuries later by Western Europeans. The state-of-the-art was and still is finer Portland Cement, first employed in Britain during the nineteenth; in the construction industry the first patents for reinforced cement and concrete systems had been registered in the second half of the nineteenth century in and outside France. By the start of the 1890s, rapidly maturing reinforced concrete and cement systems had begun to assert themselves in *Belle Époque* construction as improved alternatives to pure metallic systems with only iron or steel components.[66]

This was in part attributable to the combined mechanism of energetic patenting and commercial promotion by François Hennebique. [67] A key series of technical innovations led to the lodging over the period 1892-3 of four Hennebique French and Belgian patents for a reinforced concrete 'fire-proof' pillar-beam combination, the beginnings of what would become a fire-resistant, structurally efficient *béton armé* monolithic system. In 1897 Hennebique updated his original patents with a more sophisticated technical description and added a new patent for a foundation piling system. His initial technical-based business development was soon followed by a marketing-led one, typified by the publication of a specialist trade journal in 1898, *Le Béton Armé*, with rapidly

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[65] Hellebois, 'Theoretical and Experimental Studies on Early Reinforced Concrete Structures', 104–6.
[66] Cyrille Simonnet, *Le Béton. Histoire d'un Matériau, Economie, Technique, Architecture.* (Éditions Parentheses, 2005), chaps 1–2.
[67] Delhumeau covers the full story of the growing Hennebique business thoroughly. Delhumeau, *L'invention Du Béton Armé : Hennebique, 1890-1914*.

increasing readership amongst architects, engineers and contractors. There were of course other inventors and innovators operating in this market, not least Frenchmen Paul Cottancin (1865-1928), whose *ciment armé* system was first patented in 1889), Edmond Coignet (1856-1915), whose *ciment armé* system was first patented in 1893, and Armand Considère (1841-1914), whose *béton fretté* system was first patented in 1901; and other reinforced concrete or cement systems, similar to if not derived from *béton* or *ciment armé.*[68] The *Monierbau* system was imported from Germany and Austria having been developed abroad using the original French Monier patent of 1877 for an iron and cement combination.[69]

Table 1.1 in the Appendices shows the reinforced concrete and cement systems used in the thirteen historic example buildings in the case studies in this thesis. The evolving systems patented by François Hennebique in 1892-3 and 1897 in France and Belgium feature in more than half of these, with an unconfirmed possibility that it was also used in an HBM in Brussels. This reflects both the prevalence of the *béton armé* system in France and Belgium at this time, but equally the greater availability of archival and other sources of evidence about structures that used it. Of the remaining four historic example buildings that definitely did *not* employ Hennebique's system, there are individual instances of the Coularou system, the *béton fretté* system, the Cottancin system (or what was probably an adaption of it) and an as yet unknown system. This provides a sufficient range of individual systems within the novel materials-system over a period starting with the completion of the since-demolished Bossut-Masurel textile factory warehouse in in 1892 in Roubaix near Lille (see the case study in Chapter 1), to the completion in 1914 of two sets of blocks in the still extant HBM complex at rue de la Saïda in Paris (see the case study of HBMs in Chapter 3). As noted, Hennebique's *béton armé* system was employed the most in the thirteen historic example buildings; this reflects the dominance of the technical and organisational systems and promotional powerhouse that was based at 1 rue Danton, Paris from 1900 onwards – indeed, François Hennebique owned one of the three apartments in his new Head Office building, as if to maintain a close personal control over the design operations on the floors above him (see the

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[68] In addition to covering Hennebique's *béton armé* system, Christophe, van de Voorde and Hellebois all provide useful information on these other reinforced concrete and cement systems. See: Voorde, 'Bouwen in Beton in België (1890-1975) Samenspel van Kennis, Experiment En Innovatie'; Hellebois, 'Theoretical and Experimental Studies on Early Reinforced Concrete Structures'; Paul Christophe, *Le Béton Armé et Ses Applications*, 2nd ed. (Beranger, 1902).

[69] Sabine Kuban, 'Innovation and Standstill - Early Application and Development of the "Monier System" in Berlin', in *Proceedings of the 5th International Congress on Construction History, Chicago, Illinois. Vol 2.*, ed. B. Bowen et al. (The Construction History Society of America, 2015), 431–38.

case study of this building in Chapter 4). Patents for the novel materials-system were a vital part of technological innovation, giving French inventors up to fifteen years in which to exploit their new products and processes before competitors could copy them. But more important than the date of their recognition by the state, was whether new patents were truly different from predecessors, and whether they were actually applied in industry within the two years allowed – if not, they ceased to exist. François Hennebique lodged his first Belgian patent in 1886 for 'fire-proof' floors made from iron and cement or concrete.[70] In 1892-3 his Belgian and French patents for an emerging *béton armé* system, as he called it, started to make a significant impact on construction, initially in the north of France. This novel materials-system employed concrete and metal in a monolithic manner for pillars, beams and slabs with flanges. The Belgian patents of 1892 are described succinctly by Hellebois with key features of steel formwork and metallic reinforcing rods and U-shaped stirrups:

> A continuous metal surface simultaneously forming the floor and ceiling is proposed in February 1892. There is now a system of concrete slab poured over a corrugated steel sheet serving as formwork. The lower part of the beam is additionally reinforced with rods. The patent of July 1892 contains all the elements of the future typical Hennebique system but at a preliminary stage. Indeed, the beam including the slab is made of concrete, the main longitudinal rebars present a round section, and transversal reinforcement is provided by the insertion of stirrups, as flat U-shape sections.[71] (Figure 1.3)

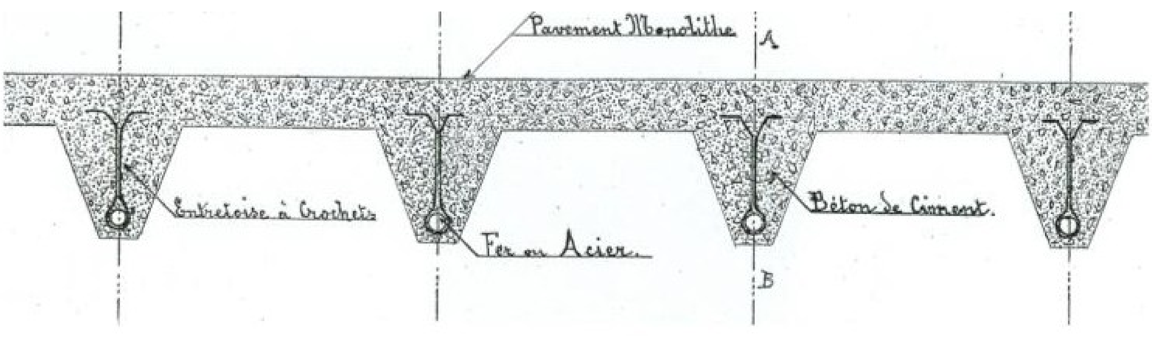

Figure 1.3: Section showing the monolithic beam-slab approach and use of U-shaped stirrups in Hennebique's 8 July 1892 Belgian patent. (Hellebois, 2013, p.71)

[70] Delhumeau, *L'invention Du Béton Armé : Hennebique, 1890-1914*, 46.
[71] Hellebois, 'Theoretical and Experimental Studies on Early Reinforced Concrete Structures', 69.

Two French patents were lodged after the two Belgian ones, in 8 August 1892 and 7 August 1893 respectively and all these steps were the start of Hennebique's own distinctive emerging approach. In 1897 updated patents were lodged to capture the ongoing improvements to a monolithic approach, as well as for new pre-cast piling.[72] The major changes to the beams since the original patents was the addition of extra (inverted) stirrups as well as bent-up rebars with fish-tail endings (see Figure 1.4); these are examined further in the case study of 'daylight factories' in Chapter 2 with specific reference to Charles Six's wool-combing mill in Tourcoing near Lille. Hellebois illustrated well the key technical components of interest in the 1897 Hennebique French patent diagram for an integrated T-beam supporting a floor slab in the *béton armé* system.[73]

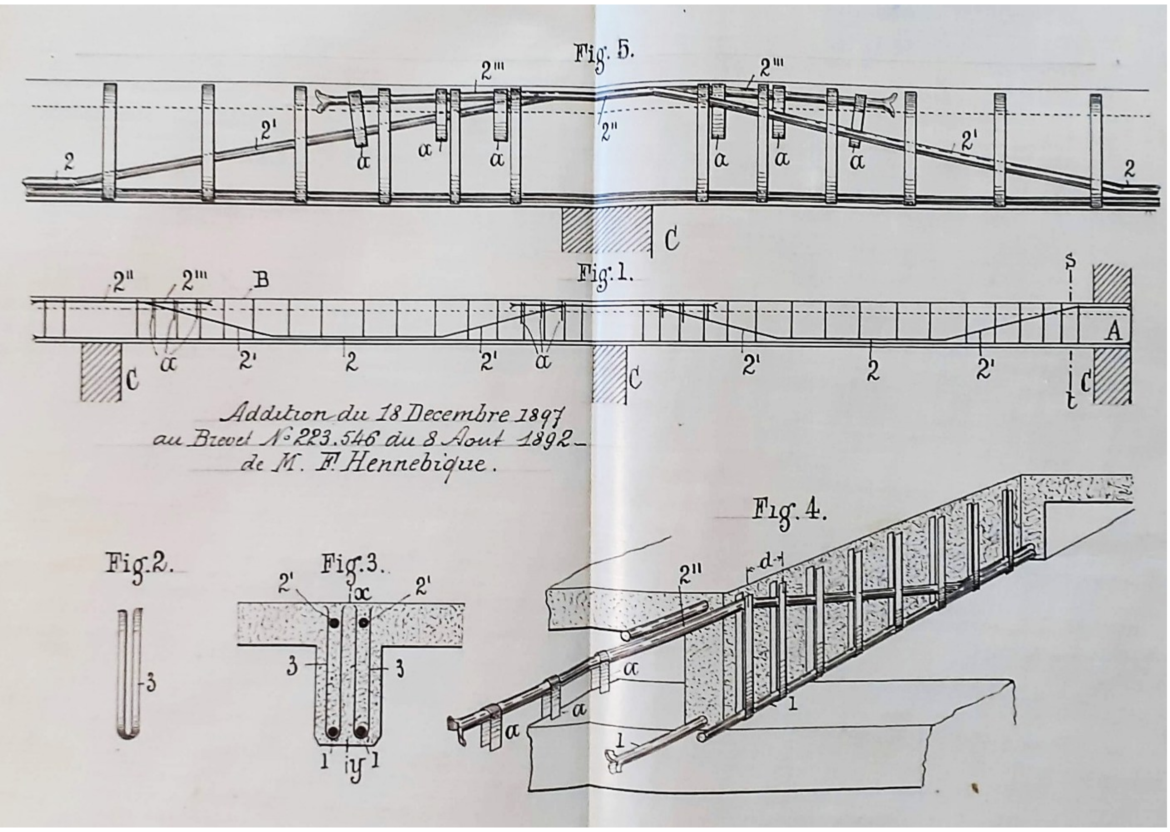

Figure 1.4: Elements of the béton armé system's T-beam in updated French Hennebique patent of 18 December 1897 with extra (inverted) stirrups as well as bent-up rebars with fish-tail endings.
(1994 035 4192, Pelnard-Considère-Caquot files, Archives Nationales du Monde de Travail)

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[72] Hellebois, 68–70.
[73] "From December 1897, the continuous T-beam is composed of straight and bent-up rebars, round and smooth with fish-tail ends, and hoop stirrups along the span. Moreover, reversed flat stirrups are added on the intermediary supports. In this last patent, Hennebique explains that the adequate combination of steel and concrete results in structural elements resistant to bending and shear solicitations [a better translation is 'movements']. The description insists on the role of each component of the beam. The longitudinal rebars support tensile stresses and their position follows the bending moment …The [hoop] stirrups counteract diagonal tension and connect the compression and tension zones of the beam … Moreover, the inverted stirrups on the supports keep the bent-up rebars in place and strengthen the building-in of the beam on the column." Hellebois, 70.

All of the improvements to the emerging *béton armé* system were aimed at making a building more robust in resisting a range of different forces produced by structural and wind loading, as well as integrating it all into what had by 1897, if not earlier, become a truly monolithic system. The French architect Louis-Charles Boileau (1837-1914)[74], who was a proponent of the Hennebique system, had already referred to the bent-up rebars in an 1895 *L'Architecture* article on the *béton armé* system, which would seem to confirm their general employment prior to the 1897 patent. Boileau introduced the metallic bars as being employed in beams and slabs, providing specific technical details verbatim from the inventor of the system:

> Mr Hennebique says on this subject: 'The function of the bent-up rebars is double: a. Together with the horizontal rebars and the stirrups, they form a solid triangle whose resistance to tensile forces increases as they advance towards the support, where these forces are at their maximum. b. They follow and meet exactly the bending force of a continuous beam with several spans.[75] (Figure 1.5)

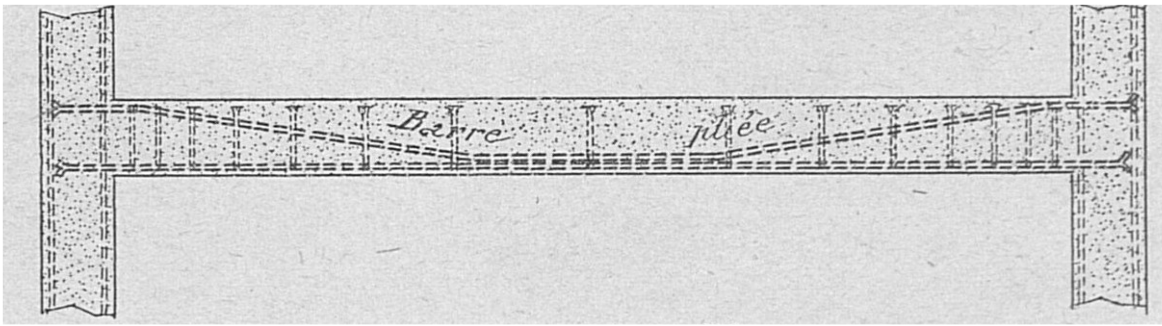

Figure 1.5: Section of béton armé system beam with bent-up rebars in 1895. (L'Architecture, 1895, 46, p.389)

The start of iron and cement as a *combined* materials-system in France originated with Joseph Monier (1823-1906) at the end of the 1870s, when he patented beams made from both materials. The most significant exploitation of this invention happened in the following decade under Monier's German patent (*Monierbau*), through non-French engineer-contractors Matthias Koenen and Gustav Adolf Wayss.[76] The French then reasserted themselves through Paul Cottancin's invention of a new *ciment armé* system first patented in 1889

[74] Boileau was the son and father, respectively, of the more famous French architects Louis-Auguste and Louis-Hippolyte Boileau, but a respected architect and rationalist thinker in his own right.
[75] Louis-Charles Boileau, 'Le Ciment Armé. Nouvelle Methode d'Application. Suite.', *L'Architecture* 8, no. 46 (November 1895): 389. « M. Hennebique dit à ce sujet: 'La fonction des barres pliées est double a. Elles forment avec les barres restées horizontales et les étriers un triangle indéformable dont la résistance à l'effort tranchant croit en s'avançant vers l'appui, où cet effort est maximum. b. Elles suivent et rencontrent exactement l'effort fléchissant d'une poutre continue à plusieurs travées.' »
[76] Kuban, 'Innovation and Standstill - Early Application and Development of the "Monier System" in Berlin', 432–33.

with eighteen further French patents until 1901, of which 1892 and 1896 are the most relevant ones (Figure 1.6). Cottancin's system used pre-made concrete bricks for the building framing, with connected surfaces made of metal meshes of about 36cm^2 with 4-5mm diameter iron wires and thin layers of cement (4-7cm), which could produce delicate vaulting effects. [77]

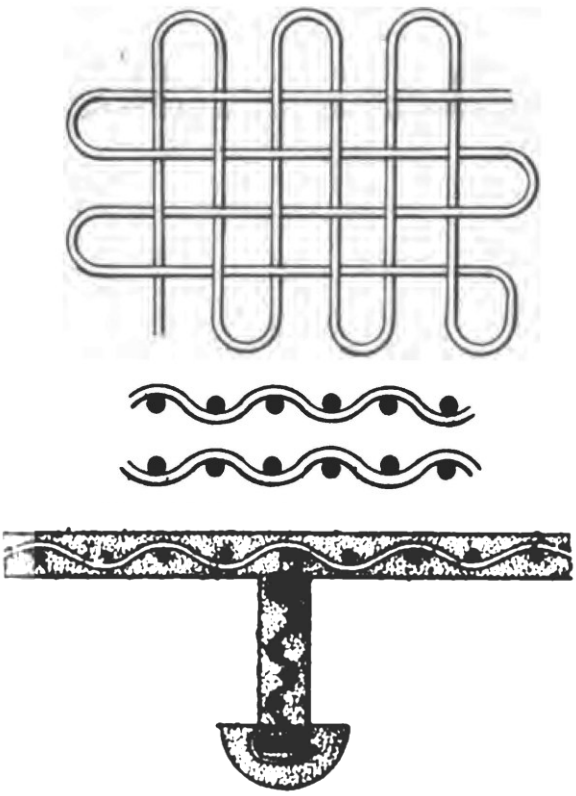

Figure 1.6: Cottancin system metal cross-mesh and a beam-slab employing it, in plan and section. (Christophe, 1902, p.20 and p.40)

A key problem with the *ciment armé* system was its slow and intricate application, hence experiencing higher labour costs, which Louis-Charles Boileau had already identified as its major weakness; this was well before Cottancin's principal supporter and Boileau's rival, the French architect Anatole de Baudot (1834-1915), finally admitted as much himself in 1904.[78]

[77] Elisabetta Procida, 'Paul Cottancin, Ingénieur, Inventeur et Constructeur', in *Édifice et Artifice. Histoires Constructives. Actes Du 1er Congrès Francophone d'histoire de La Construction*, ed. A. R. Carvais et al. (Picard, 2010), 600. Cottancin had participated alongside the French architect Charles-Louis Ferdinand Dutert (1845-1906) in the construction of the *Galerie des Machines* at the 1889 *Exposition Universelle* in Paris. Gillet, 'Conception et Confection. Une Histoire Matérielle Du Revêtement Céramique Des Immeubles Parisiens (1900-1914)', 221–22.
[78] Gillet, 'Conception et Confection. Une Histoire Matérielle Du Revêtement Céramique Des Immeubles Parisiens (1900-1914)', 226.

Armand Considère's patent of 1901 (updated in 1904) for the *béton fretté* system announced his entry into the field with a reinforced concrete system employing in its columns a circle of steel rebars connected by a spiralling metal wire; the French term *fretté* is literally translated as 'shrink-fit', so in this context describes more the effect of the concrete rather than the internal structure.[79] The contrast between the technical design of Considère's and Hennebique's columns in their *béton fretté* and *béton armé* systems is shown in Figure 1.7 taken from an original drawing in the Pelnard-Considère-Caquot files held at the *Archives Nationales du Monde de Travail* (1994 035 4192).

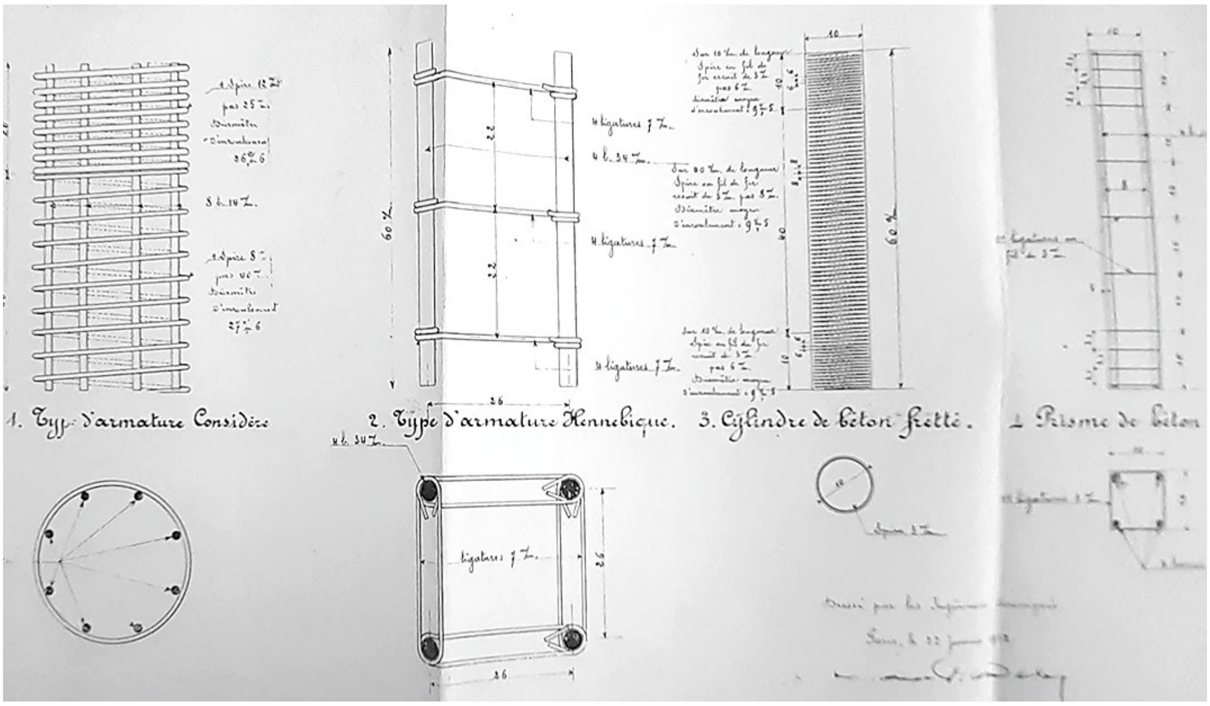

Figure 1.7: Comparison of columns, including cross-sections, using the cylindrical béton fretté system with spiral reinforcing (extreme left and centre right) and the contrasting béton armé system (centre left and extreme right). (1994 035 4192, Pelnard-Considère-Caquot files, Archives Nationales du Monde de Travail).

In essence, the *béton fretté* system, on the far left and centre right of the diagram, had circular (initially octagonal) finished columns with more longitudinal metal bars; but most critically, because of the continuous spiral tie, it was more resistant to shear forces than the separated transversal ties connecting the rectangular cross-section of the *béton armé* system, centre left and far right. The use of a spiral tie was not a completely original idea; however Considère's 1901 patent for the *béton fretté* system had developed the concept into a novel system using soft steel that was distinct from Hennebique's. This was certainly contested for foundation piles, which employed the same principles as columns. It seems that the use of the *béton fretté* system spread

[79] Hellebois, 'Theoretical and Experimental Studies on Early Reinforced Concrete Structures', 55.

rapidly, perhaps linked to the fact that as a public servant Considère was not initially allowed to profit from his patent (see the examination of the patent disputes between Hennebique and competitors later in the chapter). Collins even makes an intriguing reference to the possible use of the *béton fretté* system (or an adaption of it) in Ernest Ransome's (1844-1917) first 'daylight factory' in North America.[80] It seems Considère, in partnership with a little-know inventor called Viennot, combined the *béton fretté* system with the latter's reinforced cement slab system to produce monolithic buildings. These included *La Cathédrale* at the Menier factory in Noisiel-sur-Marne (completed in 1908, see the case study of 'daylight factories' in Chapter 2), as well as the *Maison des Dames des Postes, Télégraphes et Téléphones* completed in Paris in 1907.[81]

1893 saw Edmond Coignet's first French patent for a reinforced cement system. His father François (1814-88) began experimenting with concrete construction in 1848, initially successfully, though he went bankrupt in 1875 as a repercussion of the Franco-Prussian War.[82] Coignet senior filed new patents for what he term *béton aggloméré* in 1879 and his son Edmond joined the business in 1887, not long after which his father died. Edmond built administrative buildings for the Suez Canal Company using the family's unreinforced materials-system, but then moved on to a new reinforced cement approach in the 1890s with the technical aid of his engineer compatriot Napoléon de Tedesco. The Belgian state civil engineer Paul Christophe (1870-1957) explained Edmond Coignet's system in detail in his comprehensive technical guide of 1902. He noted that the thin slabs were the result of a network of straight criss-crossing rebars similar to those used by the Monier system. The beams were generally molded in advance independently of the slabs and set up as ordinary joists.

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[80] Collins' statement is yet to be substantiated by subsequent researchers: "From 1900 to 1902, however, [Ransome] developed a system of construction which constituted the American prototype of the reinforced concrete frame, whereby the mass wall disappeared entirely in favour of a basic structure consisting merely of a series of columns and floors, between which thin concrete curtain walling could subsequently be cast in situ as required. This system, patented in 1902, was first put into effect in the Kelly and Jones machine shop at Greensburg, Pennsylvania (now the Walworth company); a four-storey factory 300 ft. by 60 ft. constructed with spirally reinforced columns based on a new system recommended by the French engineer, Armand Considère." Collins, *Concrete. The Vision of a New Architecture*, 63. An adaption from the *béton fretté* system may also have been used in the columns of the world's first reinforced concrete skyscraper, the Ingalls Building, completed in Cincinnati in 1903. Carl W. Condit, 'The First Reinforced-Concrete Skyscraper: The Ingalls Building in Cincinnati and Its Place in Structural History', *Technology and Culture* 9, no. 1 (January 1968): 18–19.

[81] 'La Maison Des Dames Des Postes, Télégraphes et Téléphones', *La Construction Moderne* 22, no. 15 (January 1907): 173–75; Viennot, 'Lettre de Viennot', *L'Architecture* 20, no. 19 (May 1907): 149.

[82] Gilbert Richaud, 'François Coignet (1814-88) and the Industrial Development of the First Modern Concretes in France', in *Building Knowledge, Constructing Histories. Proceedings of the 6th International Congress on Construction History*, ed. Ina Wouters et al., 2018, 1121–28.

The metal core of the beam was made of round iron stirrups, which went round the lower bar and came out of the beam and fold up to tie themselves onto the metal mesh of the slab (Figure 1.8).[83]

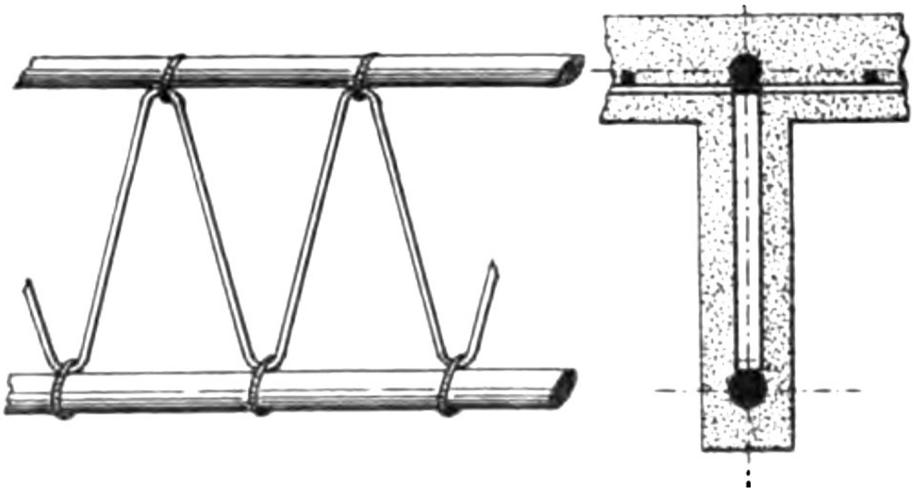


Figure 1.8: Edmond Coignet's T-beam system (right) showing the strapping connecting its rebars. (Christophe, 1902, p.36)

There are no patent records for the Coularou system, which was used in a single example historic building, the former wool conditioning premises now *La Condition Publique*, completed in Roubaix, Lille Metropole in 1901 (see the case study of four buildings in a new urban design approach in Chapter 5 and Figure 1.9). It appeared to use concrete rather than cement, with connecting internal flanges inside the beams that were angled at 45 degrees much like the stirrups of the American Trussed Concrete Steel Company's system.[84] Richaud notes that the French architect Tony Garnier employed the Coularou system for the first floor of a dairy building completed in Lyon in 1905.[85]

[83] Christophe, *Le Béton Armé et Ses Applications*, 36–37.
[84] Christophe, 47.
[85] Gilbert Richaud, 'The First Modern Concretes and the Rise of New Aesthetic Paradigms in 19th-Century France', Changing Cultures. European Perspectives on the History of Portland Cement and Reinforced Concrete, 19th and 20th Centuries (London: CRC Press, 2023), 99.

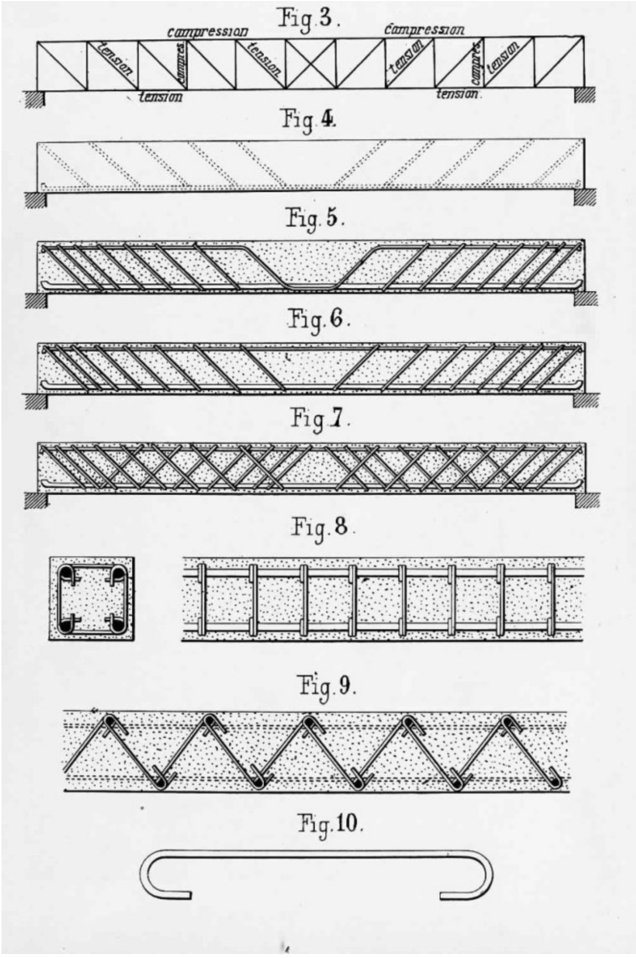


Figure 1.9: Coularou reinforced concrete system beam sections showing the 45 degree internal flanges. (Coularou, n.d., p.6)

While not employed for the thirteen historic example buildings in the case studies in the thesis, the *maison à gradins* system for a new set-back building type invented by French architects Henri Sauvage (1873-1932) and Charles Sarazin (1873-1950) was patented in France in 1912 (No 439292, see Figure 1.10). The system was employed by them for the first time a year later at the *immeuble* at 26-8 rue Vavin in Paris, referenced in the application of the historical mechanism in Chapter 6; Paul Piketty's *ciment armé* system was used for the construction of that building framing and a 1911 patent for the system (No 426863) records it as using soft steel in the rebars.

Edmond Coignet and a colleague Coisseau had patented a new system in 1894 for reinforced concrete pre-cast piles, but they did not apply it, hence François Hennebique's own patent for piling in 1897 became the predominant one in the industry.[86] This approach changed when at some point before 1902 an engineer

[86] Armand Considère, 'La Société de Fondation Par Compression Mécanique Du Sol Contre Le Béton Fretté' (Considère, 1911).

named Dulac patented the use of specially shaped weights to create moulded holes into which liquid concrete was then poured and metal framing could be inserted as required – the concrete would, once set, form a solid bloom at the base, providing even more stability in the softest ground where there was little hope of reaching any type of firm anchor – riverine settings would be a typical location.[87] The *Société Anonyme des Fondations par Compression Mécanique du Sol* (*Compressol*) was established separately by Hennebique to exploit the Dulac patent.[88]

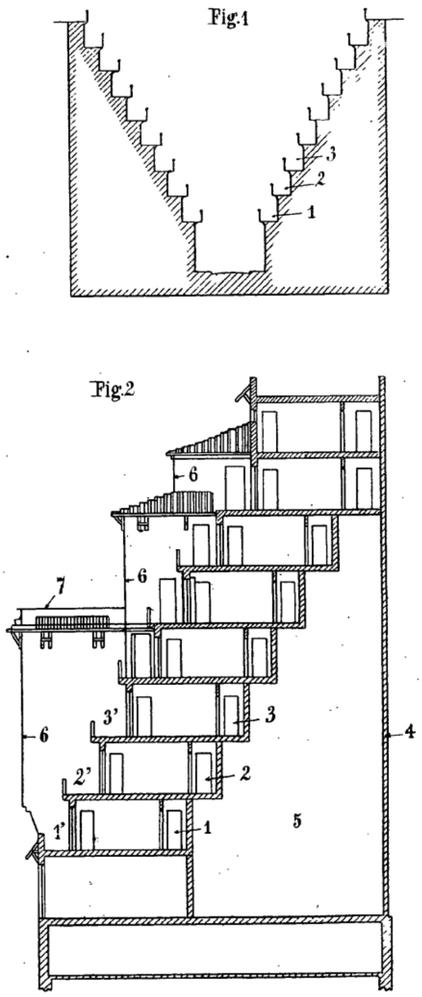


Figure 1.10: Sauvage & Sarazin's 1912 French patent for the maison à gradins system. (439292, INPI)

[87] Armande Hellebois, Yves Rammer, and Jean-Claude Verbrugge, 'Concrete Piling: Major Developments in the Historical Practice of Pile Foundations', in *Nuts and Bolts of Construction History, Proceedings of the Fourth International Congress on Construction History*, ed. R. Carvais et al. (Editions Picard, 2012), 5.
[88] Compressol, 'Problèmes Des Fondations' (La Société de Fondation par Compression Mécanique du Sol, n.d.).

Patent disputes[89]

Disputes between the inventors of industrial patents for the novel materials-system are another source of information to the researcher examining this key component of early industrial standards. Table 1.2 lists ten French legal cases involving François Hennebique or *Compressol* during the period 1902-14, either as plaintiff, accused or appellant and the majority connected to the use of reinforced concrete piling systems.

Table 1.2: Legal cases involving Hennebique or Compressol, 1902-14

Decision year	Litigants	Outcomes for Hennebique/*Compressol*
1902	Cottancin vs Hennebique	Cleared his name against accused breach of Cottancin's 1889 patent for *ciment armé.*
1903	Hennebique vs Mollet & Boussiron, Boussiron & Garrix et Piketty	His general patents for *béton armé* no longer applicable in France.
1909	Hennebique vs Piketty & Gittard Coignet & Coiseau vs Hennebique	Lost his case for alleged breach of his 1897 piling patent. His breach of their 1894 piling patent recognised by the court.
1911	Hennebique vs Piketty & Gittard, Coignet & Coiseau. Considère vs *Compressol* Hennebique vs Ministère de la Marine (Toulon)	Won his appeal against both 1909 judgements. *Compressol* cleared of defamation charges. Won his case for breach of his 1897 piling patent.
1912	Hennebique vs Considère, Menier, Combe, Société Générale d'Entreprises	Won his case for breaches of his 1897 piling patent.
1913	Ministère de la Marine (Toulon) vs Hennebique	Lost in an appeal against 1911 judgement.
1914	Considère, Menier, Combe, Société Générale d'Entreprises vs Hennebique	Lost in an appeal against 1912 judgement.

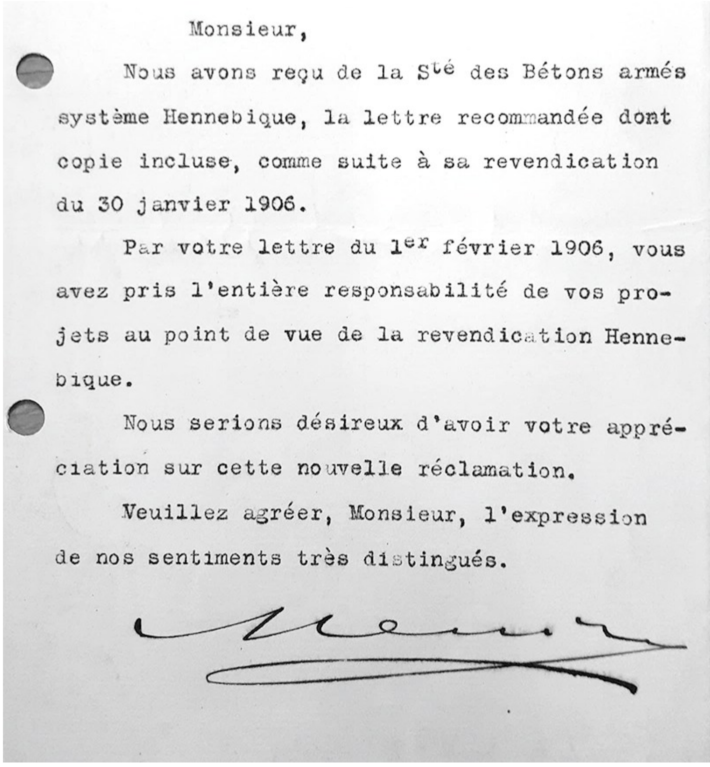
The principal source information is from legal correspondence and related materials in the Pelnard-Considère-Caquot files held at the *Archives Nationales du Monde de Travail* in Roubaix (1994 035 4192 and 1994 035

[89] This sub-section is a synopsis of the researcher's conference paper: Nick von Behr, 'The Patent War between François Hennebique and Armand Considère: Competing Reinforced Concrete Systems in "fin de Belle Époque" France', in *Timber and Construction: Proceedings of the Ninth Conference of the Construction History Society*, ed. James W.P. Campbell et al. (Construction History Society, 2022), 373–85.

4193). What was the rationale for bringing these cases to court and appeal? It appears there were three main reasons for undertaking what could become time-consuming and expensive legal action against a commercial competitor: the terms of a patent; defamation; politics. The first reason was because the terms of an existing French patent for reinforced concrete was either being breached or was coming to the end of its 15 year life, hence the commercial protection it offered would cease – in certain cases it might be beneficial to accrue as much financially from competitors through the threat of legal action, or if ignored, by following through with, hopefully, court-imposed compensation. This would seem to have been a key reason behind most of the original cases, whether initiated by Hennebique or others. Once Hennebique led the way, reinforced concrete systems had become a highly competitive section of the French construction market from the 1890s onwards.

As an illustration, the famous Menier Chocolate Factory in Noisiel-sur-Marne near Paris employed Considère's *béton fretté* system for a new mill building, *La Cathédrale,* and its *passerelle* across the River Marne completed in 1908 (see the 'daylight factories' case study in Chapter 2). These works became the subject of the main legal dispute between François Hennebique and Armand Considère between 1911 and 1914. In 1906 Hennebique had written to the head of the chocolate empire, Henri Menier (1853-1913), alleging that he was planning to use a piling system based on his own 1897 patent. Menier sought the advice of Considère, who reassured him that the piling used was not in breach of the patent, and so he replied to this effect – nothing was heard about the matter until five years later, when Henri Menier received a further letter from Hennebique demanding compensation equivalent to 10% of the project cost, with the threat of legal action if this was not resolved amicably (see Figure 1.11).

Linked to the first reason, part of a product's value was connected to its producer's reputation, and litigators knew that they could employ (the threat of) legal suits as a weapon to undermine those of their competitors. Hence the second reason, defamation, applied to Considère's case against *La Societe de Fondation par Compression Mecanique du Sol* (which owned the *Compressol* mechanised piling system). This reinforced concrete foundation company was run by Hennebique from his Paris headquarters and had published a pamphlet, probably in 1908 or earlier, with text and photographs criticising the *béton fretté* system, to which Considère had responded with his own publication. He lost his defamation case in 1911 because the judges were convinced that he had not sufficiently applied his system at the time Compressol had published their pamphlet. However, he and Menier, together with other parties, won their combined case against Hennebique on appeal in 1914.


Monsieur,

Nous avons reçu de la Sté des Bétons armés système Hennebique, la lettre recommandée dont copie incluse, comme suite à sa revendication du 30 janvier 1906.

Par votre lettre du 1er février 1906, vous avez pris l'entière responsabilité de vos projets au point de vue de la revendication Hennebique.

Nous serions désireux d'avoir votre appréciation sur cette nouvelle réclamation.

Veuillez agréer, Monsieur, l'expression de nos sentiments très distingués.

Figure 1.11: 10 May 1911 letter from Henri Menier to Armand Considère about Hennebique's compensation claim for breach of his 1897 piling patent. (1994 035 4192, Procès Hennebique, Pelnard-Considère-Caquot files, Archives Nationales du Monde de Travail)

Politics was also an impetus for legal action. This encapsulated the personal clashes between the main competitors, but also between their networks and alliances in industry and the ruling echelons of French society. When Hennebique threatened to sue such a highly respectable Frenchmen as Henri Menier, he was taking on more than just Considère as a business rival. The influence of the political factor broadened as cases entered the appeals system, but also as the prospect of war with Germany became more likely; it focused on the supremacy of French invention and innovation over foreign competition. In these circumstances it is difficult to understand why Hennebique, a Frenchman, who even though he always claimed to be a Belgian at heart, should have risked pursuing the French *Ministère de la Marine* in a breach of patent case which he ultimately lost on appeal in 1913 just before war broke out.

1d. Structural specifications

'Structural specifications' were a key component of early industrial standards during the *Belle Époque*. What is meant by this term is that they encapsulated the *structural* aspects of written building specifications and accompanying drawings that described the planned technical design, materials and workmanship for a construction project. All of this might be supplemented by pricing schedules and contractual obligations, which would collectively comprise the main legal paperwork for a construction project. For public commissions, the written and drawn building specifications and an attached price schedule could provide a necessary minimum of detail for competitive contractor tendering, based as it usually was on the lowest overall price offered for the job; this assumed that there was pre-vetting of trusted bidders and subsequent adjustments to bids to ensure genuine comparability.

A conference paper by Bertels and de Jonge studied the evolution of tenders for public construction in nineteenth-century Belgium at various governmental levels.[90] The authors referenced the 'Handbook of Specifications or Practical guide to the Architect, Engineer, Surveyor and Builder, in drawing up Specifications and Contracts for Works and Constructions' by the British architect Thomas Leverton Donaldson (1795-1885), who had co-established RIBA as the professional body for his peers, and was appointed the first British professor of architecture in 1841.[91] Donaldson's book described in detail guidelines for drafting written building specifications and contracts, as well as 46 examples from building projects in England, Ireland, Scotland and France; these include substantial details of the structural requirements for the construction of the New Palace of Westminster under British architect Sir Charles Barry (1795-1860). Donaldson asserted, quite rightly, that written building specifications were not sufficient to understand the technical design of a building, for which detailed design drawings were required from the architect (and, one assumes, for more complex structures, from an engineer) – a copy of these last would be used by the selected contractor, with reference to the building specifications finally agreed and employing his on-site working knowledge and communication of this to his workforce (whether in writing, sketched or via spoken instructions). Some of the historic example buildings illustrate the importance of structural specifications as the technical aspects of these documents, accompanied by formal drawings or even quick sketches of the structure as it was being

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[90] Inge Bertels and Krista De Jonge, 'Building Specifications and the Growing Standardizing of Public Regulation in Nineteenth-Century Belgium', in *Proceedings of the Third International Congress on Construction History*, ed. Karl-Eugen Kurrer, Werner Lorenz, and Volker Vetzk (Brandenburg University of Technology Cottbus, 2009), 197–204.

[91] Thomas Leverton Donaldson and W. Cunningham Glen, *Handbook of Specifications: Or, Practical Guide to the Architect, Engineer, Surveyor, and Builder, in Drawing up Specifications and Contracts for Works and Constructions. Illustrated by Precedents of Buildings Actually Executed ... Preceded by a Preliminary Essay, Forms of Specifications and Contracts, &c. ...* (Atchley and Co., 1860).

designed and built. It is important to stress that this initial process of collating and applying technical information about the structural aspects of a building formed a key component of early industrial standards for reinforced concrete and cement systems. Evidence of structural specifications can be particularly sketchy for non-procured construction projects and for this reason, as well as others, they are not as significant in the story of early industrial standards as the emergence of industrial patents for the novel systems. We do, however, have access to a unique historical document for the Bossut-Masurel textile factory warehouse in Roubaix near Lille which is examined in the following case study.

Case study: The Bossut-Masurel textile factory warehouse, Roubaix near Lille (1892)

This since-demolished textile factory warehouse was commissioned in 1892 by the Roubaix-based textile tradesman Émile Bossut-Masurel (Figure 1.12). While Maury had posited that a mill completed in 1893 at Don-Saighin in the *Nord* region was the first significant building to employ the *béton armé* system in that area of France, he noted as Cusack and then Delhumeau before him, the pre-existence of the Bossut-Masurel textile factory warehouse.[92] The building had first featured on the cover of the fifth edition of *Le Béton Armé* in 1898 when it was described as "1892. Shipping hall and store of MM. Bossut father and son, in Roubaix. First application of beams of long span (10m)."[93]

Hennebique confirmed the following year, in an annual conference address to his growing network of agents and other professionals, that he had used the finished warehouse to help promote his *béton armé* system in the northern region of France in which Roubaix is to be found:

> Mr. Bossut's stores in Roubaix. This is the first industrialist who entrusted me with post-fire work in Roubaix. It is a hall of 20m < 10m. The floors are calculated for 500 kilos per square metre. It was

[92] Gilles Maury, 'Effet Phenix. Les Architectes Du Nord de La France Au XIXe Siècle et l'incendie Industriel, Un Enjeu Professionel?', in *Risques Industriels. Savoirs, Régulations, Politiques d'assistance Fin XVIIe-Debut XXe Siècle*, ed. Thomas Le Roux (Presses Universitaires de Rennes, 2016), 63; Patricia Cusack, 'Reinforced Concrete in Britain: 1897-1908' (University of Edinburgh, 1981), 110; Delhumeau, *L'invention Du Béton Armé : Hennebique, 1890-1914*, 33.

[93] 'Des Vues Photographiques de La Couverture Du Béton Armé', *Le Béton Armé* 1, no. 5 (October 1898): 6. « 1892. Halle d'expédition et magasin de MM. Bossut père et fils, à Roubaix. Première application des poutres de grande portée (10m). »

these tests that were attended by the Engineers and Architects who were interested in me in the North.[94]

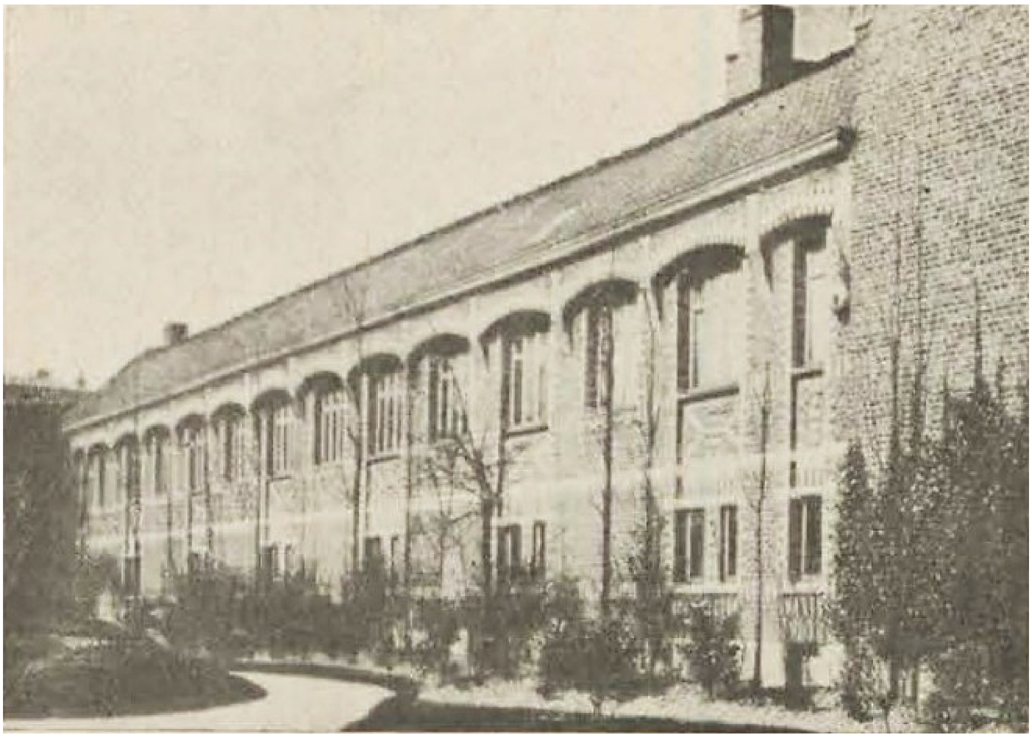

Figure 1.12: Undated photograph of Bossut-Masurel textile warehouse, Roubaix (unknown architect, 1892), showing the architectural features behind which sat a béton armé system building framing. (Le Béton Armé, 12, 1899, plates)

The 20m length of the building seems to have been an underestimate as according to the building specifications it was planned to reach 28.8m, and this would seem to match the proportions of the photograph shown in Figure 1.12, as well as tying in better with the final number of windows. A subsequent 1899 tribute in *Le Béton Armé* to the deceased eldest son of François Hennebique, Édouard, noted the latter's key role in constructing the warehouse as lead contractor, as well as the importance of the structure's building framing and floors as an early example for the expanding business:

[94] Hennebique, 'Troisième Congrès Du Béton de Ciment Armé. Séance Du Mardi Soir 24 Janvier 1899.', 6. « Magasins de M. Bossut à Roubaix. Voilà le premier industriel qui m'a confié des travaux après incendie, à Roubaix. C'est un hall de 20m < 10m. Les planchers sont calculés pour 500 kilos par mètre carré. C'est à ces essais qu'assistaient les Ingénieurs et Architectes qui m'ont porté intérêt dans le Nord. »

> [Édouard Hennebique] personally directed as a contractor the first works entrusted to his father, in Roubaix, at the end of 92-93. It is therefore to him that belongs the honor of having been the first to build reinforced concrete frames.[95]

Hennebique senior spoke about the building a year later at the *Quatrième Congrès du Béton Armé* held to coincide with the 1900 *Exposition Universelle* in Paris.[96] Once more, the significant load-bearing capacity of the structure was emphasised by the French inventor, as well as the fact that it was their first project for reinforced concrete floors and worth 23,000 francs. In a footnote to the record of this address published in *Le Béton Armé*, Hennebique added that he made the *cahier des calculs* (technical workbook) for the building available to the 1900 *Exposition Universelle* jury, the first time he had publicised these so openly, though admittedly still to a limited audience.[97] The technical workbook containing calculations for the original structural specifications for the Bossut-Masurel textile factory warehouse, signed by François Hennebique on 21 September 1892 in Brussels, is held at the *Centre d'archives d'architecture contemporaine* in Paris (CAAC 076 Ifa 2933/4, Figure 1.13). The unique document includes a plan for the basement of the building (expanded in Figure 1.14) showing the grid-like structure of *béton armé* columns and beams referred to in the *Le Béton Armé* articles.

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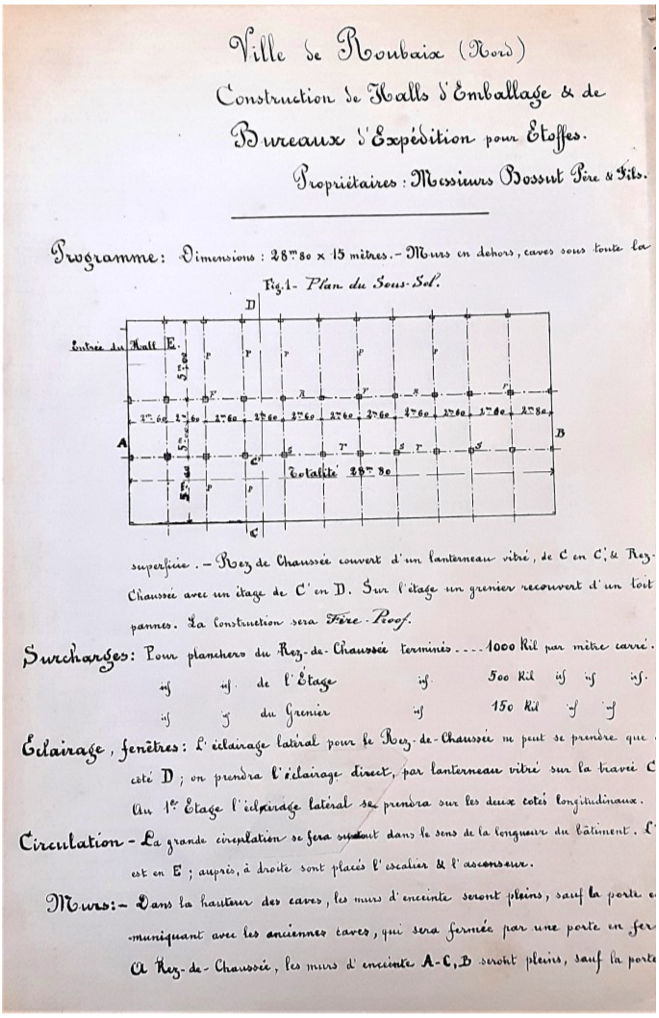
[95] François Hennebique, 'Nécrologie Pour Édouard Hennebique', *Le Béton Armé* 2, no. 15 (August 1899): 1. « [Il] dirigea personnellement et comme entrepreneur les premiers travaux confiés à son père, à Roubaix, fin 92-93. C'est donc à lui que revient l'honneur d'avoir le premier construit des charpentes en béton armé. »
[96] François Hennebique, 'Quatrième Congrès Du Béton Armé. Séance Du Dimanche 19 Août 1900.', *Le Béton Armé* 3, no. 28 (September 1900): 4.
[97] Hennebique, 4.



Ville de Roubaix (Nord)

Construction de Halls d'Emballage & de Bureaux d'Expédition pour Etoffes.

Propriétaires : Messieurs Bossut Père & Fils.

Programme : Dimensions : 28m 80 x 15 mètres. – Murs en dehors, caves sous toute la

Fig. 1 – Plan du Sous-Sol.

superficie. – Rez de Chaussée couvert d'un lanterneau vitré, de C en C', & Rez-Chaussée avec un étage de C' en D. Sur l'étage un grenier recouvert d'un toit pannes. La construction sera Fire-Proof.

Surcharges : Pour planchers du Rez-de-Chaussée terminés . . . . 1000 Kil par mètre carré.
id. id. de l'Étage id. 500 Kil id. id. id.
id. id. du Grenier id. 150 Kil id. id.

Eclairage, fenêtres : L'éclairage latéral pour le Rez-de-Chaussée ne peut se prendre que côté D ; on prendra l'éclairage direct, par lanterneau vitré sur la travée C
Au 1er Étage l'éclairage latéral se prendra sur les deux cotés longitudinaux.

Circulation – La grande circulation se fera surtout dans le sens de la longueur du bâtiment. L' est en E ; auprès, à droite sont placés l'escalier & l'ascenseur.

Murs : – Dans la hauteur des caves, les murs d'enceinte seront pleins, sauf la porte c-muniquant avec les anciennes caves, qui sera fermée par une porte en fer
Au Rez-de-Chaussée, les murs d'enceinte A-C, B seront pleins, sauf la porte

Figure 1.13: Cover of technical workbook, the Bossut-Masurel textile warehouse, Roubaix (unknown architect, 1892). (076 Ifa 2933/4. CNAM/SIAF/Cité de l'architecture et du patrimoine/Archives d'architecture contemporaine)

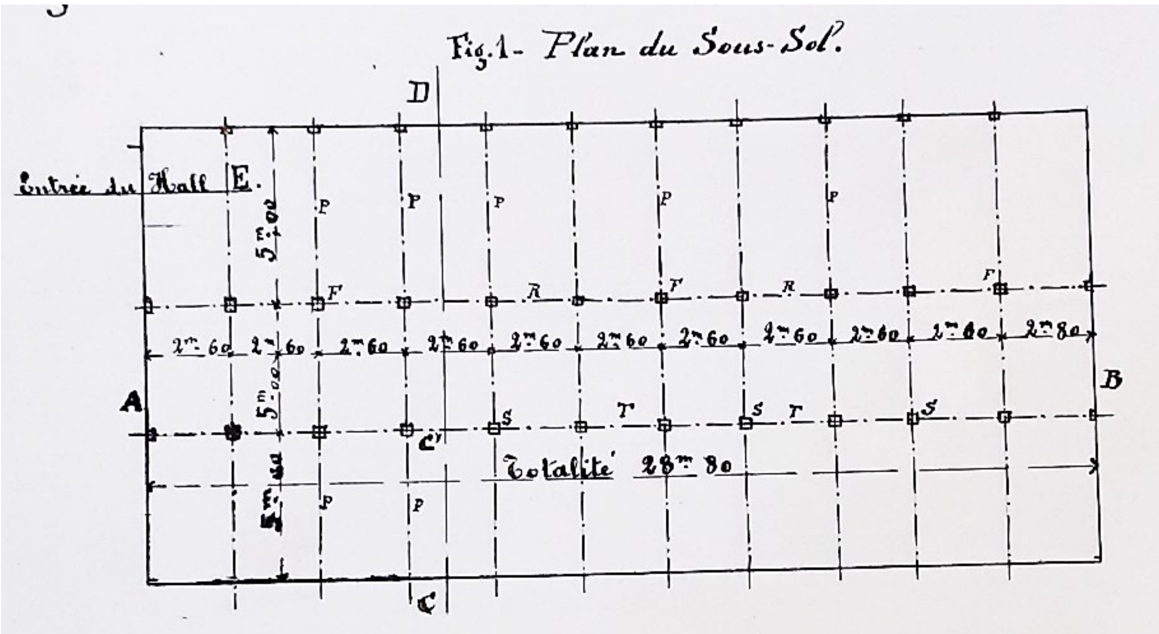


Figure 1.14: Expanded basement plan for Bossut-Masurel textile warehouse, Roubaix (unknown architect, 1892), showing the grid pattern for the béton armé system columns and beams.
(076 Ifa 2933/4. CNAM/SIAF/Cité de l'architecture et du patrimoine/Archives d'architecture contemporaine)

The basement plan shows that there are two rows of columns between the longitudinal side walls at A and B; wall A was to be newly built from brick and wall B was to be a party wall with an existing building in the Bossut-Masurel textile factory complex (seen to the right in the photograph of the building in Figure 1.12). Ten 15m transversal beams would span the building's width at ground floor level; each of these would be held at its end by the brick walls D and C and with support from additional intersecting pillars along the lines AB and FRFRF. The ten transversal beams were designed to interconnect with further cross-beams, and all of this reinforced concrete building framing would support an integrated ground floor made of reinforced concrete beam-slabs with a load-bearing capacity of 1000 kilograms per square metre; so in fact twice as much as the 500 kilos quoted by Hennebique for the subsequent floors of the building. The open arrangement of the hall permitted greater freedom of movement for delivery and pick-up vehicles in and out of the space. The plan and accompanying calculations make clear that only the basement columns at AB would continue above the ground floor level; this explains why the row of beams supporting the first floor slabs would span the 10m overall width of the building, compared to the extended 15m width at ground floor level. It appears that a glazed roof would cover the 'missing' 5m extension. The whole building would have an attic within a traditional vaulted roof which may have provided additional structural support.

It is difficult to tell from the available evidence how precisely the warehouse's design (and build) aligned with the *béton armé* system as it was being developed by Hennebique at the time – sight of the actual building today might have helped, or at least interior photographs during and/or after construction. According to Hellebois, and connected to the earlier description of Hennebique's patents in this chapter, the following were the key features of the *béton armé* system at the initial stage in its development in 1892-3: a continuous metal surface forming both the floor and ceiling; a concrete slab poured over a corrugated steel sheet used as formwork; and reinforcement bars for the lower parts of beams which also had flat U-shape stirrups to provide additional sheer resistance. There are 'cut and paste' diagrams of key beam and slab components in the original technical workbook for the Bossut-Masurel textile warehouse which are accompanied by engineering design details (Figure 1.15).

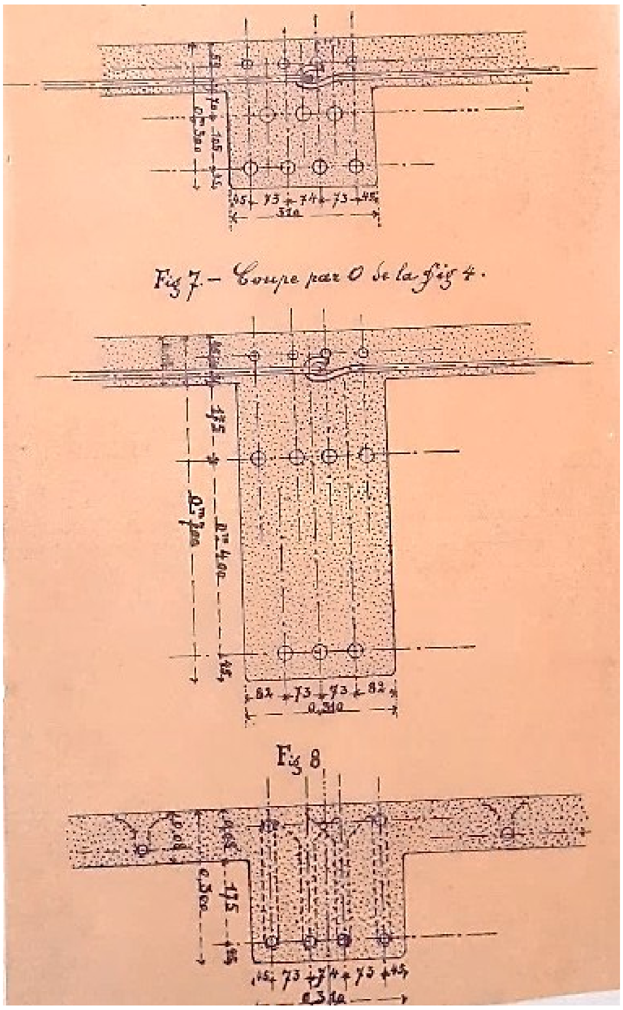


Figure 1.15: Components for Bossut-Masurel textile warehouse, Roubaix (unknown architect, 1892), showing variations in the metallic reinforcing for integrated béton armé system beams and slabs.
(076 Ifa 2933/4. CNAM/SIAF/Cité de l'architecture et du patrimoine/Archives d'architecture contemporaine)

These collectively appear to show a more complex set of integrated beam and slabs than in the 1892-3 Belgian and French patents, which allow a greater number of metallic rods or bars and U-shaped stirrups for increased loading requirements, so supporting the weight of moving lorries with up to 4000 kilos of textiles being loaded on them in the ground floor hall. All of this would seem to support a view that the warehouse's building framing and floors were constructed at an important transitional stage in the *béton armé* system, more developed than described in the 1892-3 patents, but prior to the completion of the first 'truly' monolithic building amongst all thirteen historic example buildings in the thesis: this was Charles Six's wool-combing mill in nearby Tourcoing (1897) (see the 'daylight factories' case study in Chapter 2).

On the building's aesthetic, as opposed to structural features, the technical workbook includes an interesting detail from François Hennebique as the document's author; in effect he was what we would term nowadays as the lead technical designer or specialist, despite his son receiving the public credit for the overall success of the project (we do not yet know who the architect was):

> Without seeking a costly luxury, the importance of the commercial house and the artistic richness of its offices make it necessary to take care in the construction of this hall and to harmonize it with those buildings that surround it. Our construction system will lead us to this result quite easily, while allowing us to make considerable savings.[98]

The same file for the building held at CAAC includes what seems to be an architect's drawing of a window (Figure 1.16), which matches the built windows shown in the photograph Hennebique presented to his 1900 audience (see Figure 1.12).

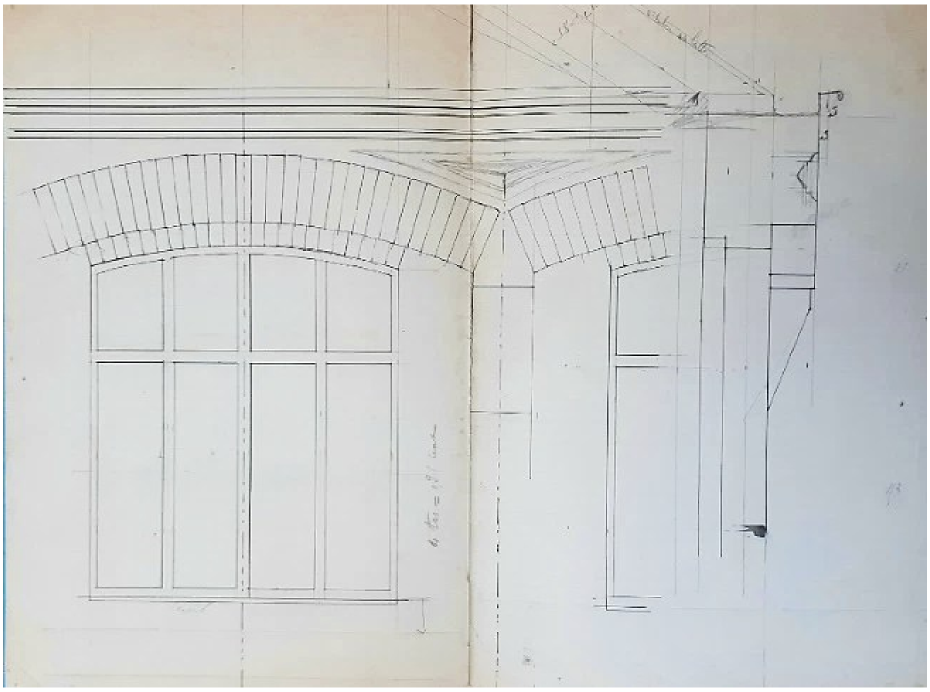


Figure 1.16: Architect's drawing of a window for the Bossut-Masurel textile warehouse, Roubaix (unknown architect, 1892) showing the arched brick canopy effect. (076 Ifa 2933/4. CNAM/SIAF/Cité de l'architecture et du patrimoine/Archives d'architecture contemporaine)

There are fourteen first floor windows shown in the photograph of the completed building, four more than the ten windows outlined in the basement plan (see Figure 1.14); this could imply that the finished beams for the floor-slabs may have ended up being more closely spaced than the design had originally intended. However,

[98] « Sans chercher un luxe coûteux, l'importance de la maison de Commerce, la richesse toute artistique de ses bureaux obligent à soigner la construction de ce Hall et à l'harmoniser avec ceux qui l'entourent. Notre système de construction nous conduira assez facilement à ce résultat, tout en nous permettant de réaliser des économies considérables. »

the ground floor windows, one floor above the basement level, seem to be irregularly spaced, creating an architectural illusion that distinguishes the two levels from each other, one more functional than the other. The verticality of the building framing is made 'visible' between the upper floor windows and matches the arched brick canopy effect above those windows and below the roof; a pronounced horizontal aspect to the building framing can be seen in the form of a long white line matching the first floor level. One can only assume that this was all the work of the unknown architect, perhaps in response to a desire for elegant office space; but there is no record of the Bossut-Masurel textile factory warehouse in local Roubaix archives, so it is currently not possible to establish a connection with any design professional. As already noted, other features of the building would have been the greater space in the delivery hall and the large windows at first floor level, which all served to create a greater daylit ambience for staff and clients – this would be of relevance to subsequent structural requirements for buildings using the novel materials-system (see Chapter 2).

1e. Technical guidance

A paper about the comparative international state of technical guidance, the third component of early industrial standards for the new materials-system, has compared the first regulations and technical guidance for reinforced concrete and cement systems in a number of European Countries at the start of the twentieth Century.[99] The authors noted that the speed of technological advance in the novel materials-system meant that the formalisation of shared technical information often lagged well behind. Of the six European countries they examine, Switzerland and Germany were early starters having adopted (quasi)national guidance for reinforced concrete and cement systems by 1904, followed by France and Belgium in 1906, the Netherlands in 1906, and the United Kingdom in 1915.

The *Swiss Engineer and Architect Society* was a voluntary membership organisation that published in January 1904 tentative rules for using reinforced concrete, with added technical explanations; these were the first voluntary technical guidelines for the new materials-system published in Europe (including the UK).[100] Rauhut examined the detailed structural analysis of a Zurich administrative building completed in 1900, before the

[99] Chapter 4 looks in more detail at the role of legally-enforceable regulations using this same paper: Stephanie van de Voorde, Sabine Kuban, and David Yeomans, 'Early Regulations and Guidelines on Reinforced Concrete in Europe (1900-1950). Towards an International Comparison.', in *Building Histories: The Proceedings of the Fourth Annual Conference of the Construction History Society*, ed. James W.P. Campbell et al. (Construction History Society, 2017), 345–56.
[100] Voorde, Kuban, and Yeomans, 3.

guidance had been completed – of particular interest is the fact that its builders had, in part, employed the *béton armé* system, but used their own technical knowledge to apply it in a local context.[101] The architect for the building had deferred to a local civil engineer (who worked for the local Hennebique *concessionaire* or concessionary) on those structural aspects which employed the novel materials-system. The engineer in turn had consulted with a Zurich professor he knew well, and then adjusted the Hennebique central design office calculations, adding new physical features to allow for a higher load-bearing capacity in the roofing structure. It is worth adding to the above observation that such an independent-minded approach was replicated in German-occupied Strasbourg, where a remarkable reinforced concrete vaulted public swimming pool was completed in 1908 by the local Hennebique *concessionnaire*, the Swiss civil engineer Eduard Züblin (1850-1916) – he had from the very start made clear to Paris Headquarters that he was more than competent in adapting the *béton armé* system to his own technical designs for buildings.[102] As for the rest of Germany, in 1907 the German Committee on Reinforced Concrete was established by the Prussian Government to determine technical guidance and potential regulations that might be applied across the whole nation.[103] In the Netherlands it appears that technical guidance for reinforced concrete and cement systems was published in 1912 by the Royal Institute of Engineers, and this seems to have continued well into the twentieth century without state involvement; even though the British had, as already mentioned, led the way in Europe on new voluntary industrial standards for steel and Portland Cement, they were behind on the regulatory aspects.[104]

The joint paper also covered both French and Belgian approaches to formulating technical guidance, first referencing the 1906 French state guidelines, and then focusing on compulsory regulations specifically connected with the new materials-system, which only properly started in both countries after the First World War.[105] Modern industrial standards as we now know them only became prevalent in France and Belgium from

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[101] Christoph Rauhut, 'Bauplatzstatik – How Structural Theory Altered Average Building Processes And How Daily Routine Influenced Structural Analysis', in *Proceedings of the 5th International Congress on Construction History, Chicago, Illinois. Vol 3.*, ed. B. Bowen et al. (Construction History Society of America, 2015), 163–70.
[102] Christiane Weber, 'Les Bains Municipaux at Strasbourg (1905-1908) - an Example of Cultural and Technical Transfer between France and Germany', in *Studies in Construction History: The Proceedings of the Second Construction History Society Conference*, ed. James W.P. Campbell et al. (Construction History Society, 2015), 199–208.
[103] Edwin A. R. Trout, 'The Deutscher Ausschuβ Für Eisenbeton (German Committee for Reinforced Concrete) 1907-1945. Part 1: Before World War I', *Construction History* 29, no. 2 (2014): 51–71.
[104] Voorde, Kuban, and Yeomans, 'Early Regulations and Guidelines on Reinforced Concrete in Europe (1900-1950). Towards an International Comparison.', 6.
[105] Voorde, Kuban, and Yeomans, 5,7.

the 1920s onwards – there were more pressing national planning reasons for this development, supported by national governments transitioning from a centralised military command to a civil market economy.

The French Commission on ciment armé[106]

At the start of the twentieth century the French state had, some might say 'at last', begun to take an active interest in the burgeoning new reinforced concrete and cement systems used for day-to-day building construction in Paris and elsewhere. This had been spurred by French architect Édouard Arnaud's (1864-1953) completion in 1900 of Hennebique's new central design office and apartments in the French capital, using the latter's *béton armé* system for the monolithic skeleton (see the case study of the building in Chapter 4); the *immeuble* was constructed with a facade made from moulded cement rather than masonry or ceramic cladding, as would have been the norm. Municipal interest was also influenced in the same year by the prominence of the new materials-system at the 1900 *Exposition Universelle* in Paris, and by a public relations disaster at this global showpiece: a pedestrian bridge using the Matrai system collapsed killing some workmen, though fortunately before it was open to the public. The French Commission on *ciment armé* was formally established in 1901 and after lengthy deliberations it produced draft standards for the production and use of the new material-systems, including *béton armé* and *béton fretté*.

In 1901 Armand Considère, who first patented his own *béton fretté* system that year, joined a majority of other eminent French civil engineers and theoreticians on the French Commission – these included Considère's mentee the state engineer Louis Harel de la Noë (1852-1931)[107], while François Hennebique and Edmond Coignet were the only other reinforced concrete and cement systems inventors present, with the architects Charles Albert Gautier (1846-1915) and Jacques Hermant (1855-1930) attending meetings as well. Considère led a sub-strand of the Commission's investigations, commissioning laboratory testing of reinforced concrete samples both in France and abroad, and focusing on the difference between his own newly-patented system, *béton fretté* and Hennebique's, *béton armé*. He would eventually take over the main secretarial duties of the

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[106] The principal source for this sub-section is Delhumeau's concise account of the work of the commission: Delhumeau, *L'invention Du Béton Armé : Hennebique, 1890-1914*, 279–94.
[107] The close professional relationship between Harel de la Noë and Considère is covered in: Francoise Sioc'han, 'Des Effets de La Houle Sur Les Ouvrages d'art: Application Des Moles Du Type "Considère" Dans La Protection Des Ports', in *Construire ! : Entre Antiquité et Époque Contemporaine : Actes Du 3e Congrès Francophone d'histoire de La Construction, Nantes, 21-23 Juin 2017*, ed. Gilles Bienvenu et al. (Picard, 2019), 325–34.

Commission after his promotion to Inspecteur Général des Ponts et Chaussées in 1902, and was the author of the final report to the Minister in 1905; it would seem that he fulfilled this role with his usual diligence as a leading state civil engineer, though given his close personal interest in his *béton fretté* system it would be reasonable to question how objectively he operated. However, Hennebique and Coignet would naturally have been expected to advance the merits of their own systems for commercial motives, so perhaps Considère saw this as a means of balancing things out between the inventors.

The state-appointed group produced what it had thought were final recommendations to the responsible Minister in 1905 on the use of reinforced concrete and cement systems in France. These were, however, independently reviewed by a special panel of the French *Académie des Sciences*, which produced its own set of recommendations, and it was these that were then signed off by the Minister. There was some subsequent controversy about the over-conservative mathematical calculations used by the special panel to determine acceptable stress limits for the new materials-systems – these would eventually be relaxed in the 1920s. The published guidance for reinforced concrete and cement, based as it was on the latest scientific and technical understanding, came into force in 1906 in France (adopted at the same time by Belgium), though only for tenders for public sector civil engineering projects. They were therefore *not* legally compliant regulations as we normally understand them, such as were developed in parts of Germany and in Switzerland (described in Chapter 4), but were rather a form of early industry standard for architect-engineers to follow if they wished to compete for state-funded construction proposals using the new materials-system.

Unlike Considère, Hennebique was sceptical about the dominant approach taken by the engineer-theoreticians on the French Commission. To some extent this reflected a general view of the contracting industry, which had relied on years of practical experience to develop new approaches, backed by the emergence of iron as a key building material in nineteenth-century France. More importantly, since Hennebique's goal was to market his own *béton armé* as superior to other construction systems, his focus was much more on emphasising better economy, greater fire resistance and structural efficiency when compared to his competitors. A mouthpiece for Hennebique's business was the editor of his in-house magazine, who later maintained that a new freestanding 100m span reinforced concrete bridge in Rome built in 1912, the *Ponte del Risorgimento*, was "the living apotheosis of reinforced concrete Hennebique system and the reduction to nothing of all the quibbles about it hidden under the cover of science."[108] As already seen, and in parallel with his membership of the Commission, Hennebique had also begun to defend his expiring patents for *béton armé* in legal suits about alleged breaches by others.

Chapter summary

The chapter emphasised the historical importance of industrial standards for engineering when considering issues related to the development of novel construction techniques. This reflected in part an initial attempt to determine whether a consensual approach to the early adoption of technical standards for new reinforced concrete and cement systems took place in France and Belgium during the *Belle Époque*, as a precursor to the global *voluntary* industrial participation coordinated by national and international standards bodies in the modern era. There is in fact little hard evidence that such a process, *as we know it nowadays*, happened in France and Belgium before the outbreak of the First World War, whereas there are stronger indications of a growing similarity with modern-day approaches *after* 1918. However, this process of examining technical standards for engineering and construction during the *Belle Époque* moved the research focus of the thesis towards an emergent form of these technical standards, described as early industrial standards. Hence three components, industrial patents, structural specifications and technical guidance, represented collectively early industrial standards for novel reinforced concrete and cement systems. Of these three components, industrial patents stood out as the key one, involving the formal codification of new technical information in a range of innovative approaches to what was becoming a novel and generic materials-system. The relationship between innovation in construction technology and the role of technical design standards was then considered with reference to recent doctoral research in this area by Angelino, based partly on an examination of historical developments as well as views sought from modern-day users.

In terms of the key industrial patents for the emerging novel materials-system, while François Hennebique's Belgian and French patents for his *béton armé* system predominated, there were alternative technical approaches that challenged his industry leadership and gradually resulted in legal disputes, as Hennebique fought back against other innovators to protect his intellectual property rights and market share. While not

[108] P. Gallotti, 'Théorie et Bluff', *Le Béton Armé* 15, no. 165–166 (February 1912): 42. « … apothéose vivante du béton armé système Hennebique et réduction à néant de toutes les arguties cachées sous le couvert de la science. »

statutory legal instruments in themselves, patents had a commercial leverage that could be backed by expert argument in front of relatively inexperienced judges, and if this was successful, could lead to punitive measures against those who imitated the proprietary systems without permission or making offers of sufficient financial compensation. Such legal measures were adopted by Hennebique from 1903 onwards as the first of his *béton armé* system patents started to reach their expiration in France; he reacted to a legal suit raised against him by Paul Cottancin accusing him of infringing the latter's own patents for his *ciment armé* system. War was declared by Hennebique on competitive reinforced concrete and cement systems, but particularly on the *béton fretté* system, the invention of his former collaborator, the French civil engineer Armand Considère.

The other two components within early industrial standards were structural specifications and technical guidance. Structural specifications comprised the main paperwork for the technical design aspects of a construction project and their relevance is illustrated through a case study of a what may have been one of the first buildings to use Hennebique's *béton armé* system during the key period 1892-3 when it was patented in Belgium and France. The other component of early industrial standards, technical guidance, was expressed through technical manuals, text books and to a lesser extent the work of the French Commission on *ciment armé*. The last-mentioned body published voluntary guidance in 1906, but it does not appear to have had a major impact on structural developments in the non-monumental, urban *Belle Époque* buildings that are the focus of this thesis. Considère had become an 'enemy party' to Hennebique because of his stringent theoretical approach to the work of the French Commission, although he had questioned the final state-sanctioned methodology for the coefficient of elasticity of the novel materials-system. Perhaps more importantly from Hennebique's perspective, Considère was a government man who had given away freely his intellectual property rights until he resigned from public office in 1906; though this was conveniently *after* he had just written his own *béton fretté* system into the published French national guidance for state-commissioned civil engineering projects.

Chapter 2: Building economics and structural requirements

Chapter 2 considers briefly the building economics of the *Belle Époque*, showing the significance of key industrialising factors, as well as the overall appetite for investment in more structurally efficient buildings constructed from the novel materials-system. The chapter goes on to examine in more depth key structural requirements associated with specific commissioner needs for new non-monumental, urban *Belle Époque* buildings employing the novel materials-system: fire resistance, structural efficiency, daylight admission and street decor. The chapter includes a case study of the architectural typology of North American 'daylight factories' and its subsequent interwar trope, including two historic example factory buildings near Lille and near Paris.

2a. The economics of building

Belle Époque France operated under the influence of a range of economic factors.[109] While by 1880 the nation had finally become a true industrial economy along the lines of world's forerunner, Britain, during the subsequent period to the outbreak of the First World War it then experienced, like many other 'catch-up' industrialising nations, the vagaries of international competition for the sale of more and more manufactured goods in ever-expanding global markets. The French agricultural sector dominated, with 45% of the total population still living from it in 1891. A post 1870s industrial slump was rectified to some extent by the mid-1890s with increasing investment in new industrial plant and machinery, though the full impact of this mini-boom is debatable.[110]

The historic cities of Lille, and neighbouring Roubaix and Tourcoing, specialised at the time in textile manufacturing and were on the fringes of a major coal-producing region of northern France, from which the output could fuel a cheap source of steam power for expanding factories. The French textile industry had been

[109] These are described in: Roger Price, *An Economic History of Modern France, 1730-1914*, 2nd ed. (The Macmillan Press Ltd, 1981); Clive Trebilcock, *The Industrialization of the Continental Powers 1780-1914* (Longman, 1981); François Crouzet, *The Economic Development of France since 1870*, vol. 1 (Edward Elgar Publishing Ltd, 1993).

[110] Trebilcock pinned the down-turn precisely to the year 1882, a result of the impact of a French wine-growing disaster attributed to a new voracious aphid. He then gave reasons for French laggardly economic growth during the *Belle Époque* when compared to its European competitors, including a lack of sufficient French entrepreneurship. Trebilcock used a successful textile family from Roubaix, near Lille as an example of this, which connects to two historic example buildings in Roubaix and neighbouring Tourcoing in the cases studies, as well as Landes' commentary about their local manufacturer building commissioners in Chapter 4. Trebilcock, *The Industrialization of the Continental Powers 1780-1914*, 189.

the second largest national employer until the late nineteenth century, when it overtook construction and took the lead; in 1906 this workforce totalled 2.6m persons overall, despite labour-saving measures achieved by introducing new manufacturing technology.[111] Roubaix and Tourcoing had a competitive advantage compared to nearby Lille, now all within the same regional metropolis, with easier access to a cheaper rural labour-force from their Flanders neighbour, particularly after that part of the Netherlands became independent Belgium in 1830; but the French Nord region was also capable of switching more fluidly than other textile centres between manufacturing the different fibres, whether wool, cotton or linen (flax) and depending on respective market booms and busts. By the start of the twentieth century, Roubaix-Tourcoing had become the dominant wool processing centre in France with a resultant reputation for manufacturing fine cloths.[112] Further south, Bullock and Read examined the Paris housing market prior to the First World War and concluded that the main economic impulses came from the settled industrial workers in the capital's growing suburbs after the post-war depression of the 1870s. However, there was a further sudden depression in the early 1880s which marked the end of a dynamic stage for the housing market and led to a subsequent decline in construction until 1910, when a new recovery was stopped by the outbreak of yet another war – it had also been accompanied by a steep rise in rents.[113]

The demand for both the metallic-based and then the novel reinforced concrete and cement systems for *Belle Époque* construction was inevitably dependent on the end user. The initial impetus for metallic building framing systems in France came from state-sanctioned works, exemplified in the capital, Paris by railway stations, libraries, markets and exhibition spaces (see Chapter 5 on the first stage of a metallic building design revolution). The economic driver in the adoption of new reinforced concrete and cement systems for non-monumental, urban buildings was demand from private industry. Hennebique had initially moved from northern France to Brussels to operate as a building contractor. While his early inventions took place in Belgium, the business only expanded once textile manufacturers in the north of France took an interest in the greater fire resistance and structural efficiency of buildings using the novel materials-system; key structural requirements that had important economic aspects to them for the enterprises commissioning the *béton armé*

[111] Price, *An Economic History of Modern France, 1730-1914*, 99.
[112] Jean-Claude Daumas, *Les Territoires de La Laine. Histoire de l'industrie Lainière En France Au XIX Siecle.* (Villeneuve d'Ascq: Presses Universitaires du Septentrion, 2004), 328–29, 366.
[113] Nick Bullock and James Read, *The Movement for Housing Reform in Germany and France 1840-1914* (CUP, 1985), 298–99.

system.[114] Bowley, when analysing the economic history of the British construction industry, focused on the development of iron-framed skyscrapers in 1880s Chicago as a significant transition point which gradually percolated across the Atlantic: the new structures allowed greater efficiency and returns on investment due to lighter foundations (in a locality with big sub-soil issues), more and wider floors, increased daylight (hence reduced cost of artificial lighting) and faster speed of construction. All of this made commissioners and builders of structures think twice about using traditional construction methods – British building contractors such as Thomas Cubitt (1788-1855) had already introduced at the start of the nineteenth century the concept of employing a standing corps of labourers, which meant that new construction projects had to be found to cover larger fixed costs from their wages.[115]

It would be reasonable to assume that the same fundamental economic principles began to operate in France and Belgium prior to the First World War for the new reinforced concrete and cement systems. Hellebois notes that at this time reinforced concrete was an economical construction material when compared with 'traditional' materials such as timber, masonry or even steel, though one wonders whether the last could really be classified as such:

> The price of 1 m³ of in-place concrete depended on the raw materials (the attractive price of cement, etc., but the high cost of the steel rebars), the technology, industrial and automation processes, the cost of labour, the means of transportation... However, the factors were too numerous and variable to allow an accurate comparison, although the authors [various professionals of the period] estimated a saving of around 25%.[116]

Initial innovation costs transitioned into satisfactory economic returns - Hennebique's goal was to market his own reinforced concrete system as superior to other construction systems, hence his focus was much more on emphasising better economy, particularly in savings due to greater fire resistance and the use of less building material volume through improved structural efficiency. Finally, as seen in the examination of patent disputes in Chapter 1, towards the end of a patent's life it might be beneficial to accrue as much financially from

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[114] Delhumeau et al., *Le Béton En Répresentation. La Mémoire Photographique de l'entreprise Hennebique 1890-1930*, 84–98.
[115] Marian Bowley, *The British Building Industry. Four Studies in Response and Resistance to Change* (Cambridge University Press, 1966), 9–12, 335.
[116] Hellebois, 'Theoretical and Experimental Studies on Early Reinforced Concrete Structures', 78.

competitors through the threat of legal action, or if ignored, by following through with court-imposed compensation for loss of earnings.

Economic, as well as societal imperatives (see Section 2), fed into the demand for new *Belle Époque* buildings that could satisfy the needs of their commissioners. Such needs had to be converted into structural requirements that informed the building design process using the novel materials-system. The term 'building science' is used by Addis as an extraneous factor in his Design Procedure model (see the Historiographic Framework), but nowadays this is associated with principally the internal environment of a building, rather than the whole physical structure. Four key 'structural requirements' associated with the novel materials-system and derived from corresponding commissioner needs were evident in the historical example buildings in the cases studies: fire resistance, structural efficiency (including within it building framing, floors and foundations), daylight admission and street decor.

2b. Fire resistance as a structural requirement

One of the biggest societal fears remains until today uncontrolled fire within urban buildings, evidenced by raging infernos in global cities of the past, or harrowing stories of death in the flames – the 1897 Paris Charity Bazaar fire killed 127 high-ranking French women and was singled out at the first world congress on fire prevention in London six years later.[117] Fire-resistant structures were highly valued in nineteenth century industrial and urban contexts, where the risks and resulting costs of conflagration could be considerable – an added benefit would have been a reduction or even removal altogether of insurance premiums, assuming the value of the new materials used was sufficiently recognised by actuaries.[118] One of the historic example buildings, the *Entrepot Royal B* Warehouse in Brussels (completed in 1906, see the case study in Chapter 5 of four buildings in a new urban design approach), was a commercial structure for storing large volumes of valuable goods, and hence the costly risk of fire damage required that special measures had to be employed.

[117] I. H. Woolson, 'Report of the Proceedings of the International Fire Prevention Congress 1903' (City of New York, 1904).

[118] Wermiel has researched building fire resistance in this period in the United Kingdom and North America. See: Sara E. Wermiel, 'The Development of Fireproof Construction in Great Britain and the United States in the Nineteenth Century', *Construction History* 9 (1993): 3–26; Sara E. Wermiel, 'America's 19th-Century British-Style Fireproof Factories Background: Fireproof and Slow-Burning Construction', *Industrial Archaeology* 27, no. 2 (2001): 23–36.

Maury examined industrial fires in nineteenth-century Northern France, including a major 1866 conflagration at 'Le Monstre', a vast textile factory owned by the Motte-Bossut family in Roubaix near Lille, and which was replaced by an iron-framed structure to prevent further such catastrophes.[119] The architect had completed the original structure using wooden building framing and this was accepted as normal practice, even though we know iron was being used in factories outside of France well before that time. The replacement building was much more in tune with such leading edge construction, though the architect is unknown. There did eventually exist a local expert in 'fireproof' techniques who could at least advise architects and contractors on what should have been termed 'fire-resistant' construction — fireproofing was not technically possible as all contemporaneous construction materials combusted eventually as temperatures increase, including concrete, with more or less serious repercussions depending on a range of factors. Maury tells us that Ernest-Maxime Meunier was active in Lille between 1867 and 1910 as the general manager of the insurance company *Union du Nord*, liaising with the largest local industrialists and their architects. Meunier wrote several books in his specialist area, including a key report on the causes of industrial fires that was published in 1864.[120] Another example in Lille, the printing premises of Louis Danel were completed in 1875 by a leading local architect, Émile Vandenbergh (1827-1909), who had studied under Henri Labrouste at *l'École des Beaux-Arts* in Paris. This impressive building had a novel iron and glass roof structure hung above non-loadbearing walls. Maury also makes due reference to the first works using Hennebique's *béton armé* 'fireproof' system in the northern region of France, particularly a mill near Douai, and the Bossut-Masurel textile factory warehouse in Roubaix (see the case study in Chapter 1).

There is an earlier academic piece by Wouters and de Bouw on 'fireproof' construction, but this time in Brussels between 1840-70.[121] This incorporated prior research by British experts on the introduction in the UK of fire-resistant industrial buildings (mainly textile) from the end of the eighteenth century onwards. Six example structures in Brussels completed in the mid-nineteenth century used various forms of iron. Individual

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[119] Maury, 'Effet Phenix. Les Architectes Du Nord de La France Au XIXe Siècle et l'incendie Industriel, Un Enjeu Professionel?' Maury's chapter contribution to a book on industrial risks in end seventeenth- to start twentieth-century France, examines the role of architects in responding structurally to the fire resistance needs of factory owners in the *Département du Nord*. The Motte-Bossut factory still stands, was extensively renovated in the 1980s and is currently the home of the French *Archives Nationales du Monde de Travail*.
[120] Maury, 52.
[121] Ine Wouters and Michael De Bouw, 'The Development of Fireproof Construction in Brussels between 1840-1870', *Industrial Archaeology Review* 28, no. 1 (July 2006): 17–31.

architects decided on the use of materials and this was exemplified by the first of these structures completed in the Brussels docks in 1847 – like the *Entrepôt Royal B* constructed more than 60 years later (see the case study in Chapter 5 of four buildings in a new urban design approach), it was a commercial warehouse for storing large volumes of valuable goods, and hence the risk of fire damage required appropriate measures; a Brussels pawnshop completed in 1867 is of similar interest as the architect decided to clad all exposed iron with plaster, brick or masonry *and* exclude all wood, hence increasing its 'fireproofing', while a piano factory built in 1870 employed non-reinforced concrete for its roof vaulting, a singular occurrence from this period.[122]

Following in the footsteps of these first metallic approaches, François Hennebique promoted his *beton armé* system to potential customers as a means of preventing commercially disastrous fires; these were particularly prevalent in those industrial sectors which used highly flammable raw materials, of which the textile manufacturing centre of Lille, Roubaix and Tourcoing was an obvious and nearby case for his business's expansion out of Brussels. As timber and unprotected iron were replaced by reinforced concrete and cement and the external walls required less load-bearing structural support in a truly monolithic system, this permitted the use of much larger continuous window spacing – which also lessened the potential fire hazard of using artificial lighting. Hennebique illustrated his system's fire-resistant properties by circulating photographs of the satisfactory outcomes of his controlled burning tests, or using examples where his competitors' systems had failed to resist sufficiently the damage of the flames. There was both a 'fear' and an economics angle to his approach which was appreciated by the Northern mill owners.[123]

Taking the historic example buildings in the case studies in this thesis, the original specification for the wool-conditioning complex in Roubaix (completed in 1901, see the case study in Chapter 5 of four buildings in a new urban design approach) included the design of a *béton armé* system precisely for fire resistance reasons, though it would be replaced by the Coularou system for the extensive roof-terracing. The same fire-resistant principles would have applied to the use of a reinforced concrete system in Charles Six's new wool-combing building in Tourcoing and *La Cathédrale* at the Menier factory in Nosiel-sur-Marne (see the case study of 'daylight factories' later in this chapter), and the extension to Banque Brunner in Brussels and the annex to the *Archives Départementales du Nord* in Lille (see the case study of four buildings in a new urban design approach

[122] Wouters and Bouw.
[123] Delhumeau, *L'invention Du Béton Armé : Hennebique, 1890-1914*.

in Chapter 5). All these premises had building commissioners who were keen to minimise fire damage to valuable contents, as well as any knock-on impact to end users of the interruption to production, sales and service processes; indeed any potential rises in insurance premiums would force the owners to increase their sales and service charges or reduce their profit margins, depending on market conditions.

2c. Structural efficiency as a structural requirement

The use of metal in construction had started to change approaches when it was fully understood that greater height of structures and wider spans (at less cost) could be achieved by using cast iron, then wrought iron and steel components, exemplified in a monumental form at the 1889 Paris *Exposition Universelle* by the Eiffel Tower and the *Galerie des Machines* (see the first stage of a metallic building design revolution in Chapter 5). The introduction of reinforced concrete and cement systems permitted even more economical and lightweight monolithic structures where the building framing could be fully integrated with the floors and the foundations. There was similarly an impact on the building plan and layout such that *redans* (tooth-like projections towards the street, derived from defensive fortifications) and other unconventional plot-shapes could be facilitated more easily. Three key components of structural efficiency are next considered, followed by an examination of how they worked together to create a monolithic structure in buildings that employed the novel materials-system.

Building framing

Building framing has been around since the first ancient structures were built from a basic 3-D supporting grid of pillars and beams with vaulting and arches added over time. Masonry and brick, even some cement or concrete, might have replaced timber in this simple structure and all would be treated as load-bearing materials wherever they were situated, supporting vast edifices such as temples and churches, or smaller private residences. Building framing needed to address any lateral or vertical load paths in the whole structure, particularly in industrial and commercial premises where vibrating machinery may be in continuous operation, in locations subject to strong winds or earth tremors, or even just large temporary or permanent live loadings due to human occupancy. Of the thirteen historic example buildings in the case studies in the thesis, nine employed reinforced concrete or cement systems for their building framing, in chronological order:

- The wool-combing mill at Charles Six's factory in Tourcoing (1897) which used the *béton armé* system.
- The extension to *Banque Brunner* in Brussels (1900) which also used the *béton armé* system.

- The *immeuble* at 1 rue Danton in Paris (1900) which employed the *béton armé* system.
- The *immeuble* at 9 rue Claude-Chahu in Paris (1903) which used the *béton armé* system.
- The HBM at 7 rue de Trétaigne in Paris (1904) which used an unknown reinforced concrete system.
- The *La Cathédrale* cocoa and sugar processing building at the Menier Chocolate Factory in Noisiel-sur-Marne (1908) which used the *béton fretté* and Viennot systems.
- The annex to the *Archives Départementales du Nord* in Lille (1910) which employed the *béton armé* system.
- The *immeuble* at 185 rue Belliard in Paris (1913) which used the Cottancin system.
- The HBM complex at rue de la Saïda in Paris (1914) which employed the *béton armé* system.

Floors

In many of the historic example buildings, the floors (and terrace-roofing if present) were made from reinforced concrete or cement systems. The *béton armé* system was used in floors with cantilevered galleries in the very similar approaches of the *Entrepôt Royal B* import warehouse in Brussels (1906) and the annex to the *Archives Départmentales du Nord* (1910) in Lille;[124] and the sheer scale and ambition of the 3000 m^2 reinforced concrete terrace-roofing for the former wool-conditioning complex, now *La Condition Publique,* in Roubaix near Lille (1901) is also impressive for its time and was supported by a unique set of 39 iron matrix pillars (these three examples are in the case study of four buildings in a new urban design approach in Chapter 5). One could speculate that local architect Auguste Bouvy (1857-1938) may have learned lessons for his approach to the flat terrace-roofing of the last historic example building from a viewing of Charles Six's wool-combing mill in neighbouring Tourcoing (see the case study of 'daylight factories' later in this chapter). The HBM at 32 rue Marconi in Brussels (1902) is an interesting example of a hybrid form that was employed to seemingly transfer the load paths from the reinforced concrete floors to a mainly brick building framing (see the case study of HBMs in Chapter 3). There is a multiplicity of archival evidence on the construction and renovation of this building, which may have been the first HBM in France or Belgium to employ either a

[124] We know from the Hennebique archives at the CAAC that the design plans for the Lille building were later requested by a Hennebique agent in Italy. Chapter 4 considers how the business was keen to exchange its centralised technical knowledge between its agents and *concessionnaires*, so one could imagine that the same principle applied to these two Brussels and Lille example historic buildings. Delhumeau, 112–34.

reinforced concrete or cement system, but unfortunately no evidence has yet fully confirmed the precise system used to construct it.

Foundations

As an important complement to building framing and floors as elements of structural efficiency, every truly permanent structure needed strong foundations to address gravitational forces, particularly if built on a slope or softer ground; piles were used on their own or to strengthen large cement slabs, that had already been employed since the early nineteenth century with some good examples in the United Kingdom.[125] French inventors began to design pre-cast reinforced cement and concrete piles formed and cured on the building site using the *béton armé*, *béton fretté* or similar suitable systems, and were then steam-hammered into the ground once the concrete or cement was fully set. Subsequently, reinforced concrete and cement foundation piling formed *in situ* was developed, including Hennebique's *Compressol* system described in Chapter 1.

Of the thirteen historic example buildings in the case studies in the thesis, only four show clear evidence of foundation type from any extant structural design drawings or other remaining elements of their original structural specifications – they are listed by system used:

- The *immeuble* at 1 rue Danton in Paris (1900) used the *béton armé* system for foundation work near the River Seine (see the case study of the building in Chapter 4).
- The *Entrepôt Royal B* import warehouse in Brussels (1906) and the first units of the HBM complex at rue de la Saïda (1914) in Paris both used the *Compressol* system in what was softer ground (see the case studies of four buildings in a new urban design approach in Chapter 5 and of HBMs in Chapter 3).
- *La Cathédrale* at the Menier Chocolate Factory in Noisiel-sur-Marne (1908) used the *béton fretté* pre-cast piling system for its riverine setting on the Marne (see the case study of 'daylight factories' later in this chapter).

[125] Good summaries of the state of knowledge in concrete foundations during the period are: Mike Chrimes, 'Concrete Foundations and Substructures', in *Historic Concrete Background to Appraisal*, ed. J. Sutherland, D. Humm, and M. Chrimes (Thomas Telford Publishing, 2001); Hellebois, Rammer, and Verbrugge, 'Concrete Piling: Major Developments in the Historical Practice of Pile Foundations'.

Monolithism

Paul Christophe had explained the value of monolithic reinforced concrete or cement structures, with particular reference to street facades, in his detailed technical guide to the novel materials-system:

> Reinforced concrete as it is used in monolithic construction can have its own architecture and it is often wrong to look elsewhere than in the affirmation of the real structure for decorative motifs. This structure, as has already been pointed out, is similar to that of metal structures; but, by the more massive aspect of the elements of the skeleton, it is closer to that *of timber framing*. All the architecture of the Middle Ages and the Renaissance shows us how much this last construction system suits the decoration of facades.[126]

Christophe emphasised the greater volume of the structural components when comparing the metallic construction systems of reinforced concrete and cement with iron and steel, hence the analogy with the use of timber for the former. Masonry, timber and brick building framing and flooring was fine for resisting the many structural vibrations of textile-processing machinery over numerous floors; but as industrial premises expanded with larger scale operations, combining reinforced concrete building framing, floors and even foundations using the same materials-system permitted the construction of a stable, self-supporting monolithic structure over a much larger volume of space. Such a building could also use non-loadbearing glazed infills to allow more natural light inside – daylight admission as a structural requirement will be considered separately in the next part of the chapter.

Table 1.3 shows ten of the thirteen historic example buildings in the case studies that might have been construed to have had a monolithic structure; such buildings would have had at least their building framing and floors constructed as integrated, self-supporting skeletons – this implied that the novel materials-system was employed holistically throughout the building, including with the foundations, rather than in a more ad hoc manner. Eight of these buildings used Hennebique's *béton armé* system for their building framing and

[126] Christophe, *Le Béton Armé et Ses Applications*, 151–52. « Le béton armé tel qu'il est employé dans le constructions monolithes peut avoir son architecture propre et c'est souvent à tort que l'on cherche ailleurs que dans l'affirmation de la structure réelle, des motifs de décoration. Cette structure, on l'a déjà fait remarquer, est analogue à celle des charpentes métalliques; mais, par l'aspect plus massif des éléments de l'ossature, elle se rapproche davantage de celle des *pans de bois*. Toute la l'architecture du moyen âge et de la Renaissance est pour nous montrer combien ce dernier système de construction offre de ressources à la décoration des façades. »

floors. The other two historic buildings were individual examples each of a Cottancin derived system and Considère's *béton fretté* system with additional features from the engineer Viennot.

Table 1.3: Historic example buildings in the case studies whose structure appeared to be monolithic

Building (Year completed)	**Systems used**	**Used in building framing**	**Used in floors**	**Used in foundations**
Bossut-Masurel textile warehouse, Roubaix near Lille (1892)	*béton armé* system	Yes	Yes	Not known
Charles Six wool-combing mill, Tourcoing near Lille (1897)	*béton armé* system	Yes	Yes	Not known
Extension to *Banque Brunner*, Brussels (1900)	*béton armé* system	Yes	Yes	Not known
Immeuble, 1 rue Danton, Paris (1900)	*béton armé* system	Yes	Yes	Yes
Immeuble, 9 rue Claude-Chahu, Paris (1903)	*béton armé* system	Yes	Yes	Not known
Import warehouse, *Entrepôt Royal B*, Brussels (1906)	*béton armé* and Compressol systems	Yes	Yes	Yes
Cocoa and sugar processing building, *La Cathédrale*, Noisiel-sur-Marne, Paris (1908)	*béton fretté* and Viennot systems	Yes	Yes	Yes
Annex to *Archives Départementales du Nord*, Lille (1910)	*béton armé* system	Yes	Yes	No
Immeuble, 185 rue Belliard, Paris (1913)	Cottancin derived system	Yes	Yes	Not known
HBM complex, rue de la Saïda, Paris (1914)	*béton armé* and Compressol systems	Yes	Yes	Yes

It is possible some of the remaining three example historic buildings in the thesis which are not included in table 1.3 might eventually qualify as being monolithic, assuming the availability of more precise details about their internal structures. Of the historic example buildings listed in table 1.3, the Bossut-Masurel textile factory warehouse in Roubaix near Lille (1892, see the case study in Chapter 1) used an early version of the *béton armé* system for its building framing and floors, together with masonry and brick walls which provided additional structural support – this approach was repeated with other buildings subsequently. The earliest historic example building in the table that used the novel materials-system in a truly monolithic way is the

Charles Six wool-combing mill completed in 1897 in neighbouring Tourcoing (see the case study on 'daylight factories' later in this chapter).

2d. Daylight admission as a structural requirement

The most obvious facet of daylight admission as a structural requirement for a historic example building, was external facing glazing usually in the form of (french) windows and skylights. Windows connected with the use of innovative reinforced concrete and cement systems in 'daylight factories' from the 1890s on, but there was also a link backwards to the increasing use of bay windows in French and Belgian urban housing during the *Belle Époque*. As will be seen in Section 2 on the societal context for construction using the novel materials-system, this in turn connected to social needs and regulatory issues. Suffice it to say in this technical-focused section of the thesis, windows were also considered as an absence of infill for reinforced concrete or cement building framing; the more windows (and doors and balconies) that existed, the less space for other types of such infill, and the greater its visual impact on the street facade and its cladding. This is exemplified well in the case study of the *immeuble* at 1 rue Danton in Paris in Chapter 4, as well as in the historic example buildings at 9 rue Claude-Chahu and 185 rue Belliard (see the case study of Parisian *immeubles* with decorative ceramic facade cladding in Chapter 5).

The wool-combing mill at Charles Six's textile factory in Tourcoing (1897) is described fully in the subsequent case study of 'daylight factories'. It was the first of all the historic example buildings to employ large rectangular windows that replaced all infill, in this case on the three floors above ground level. François Hennebique explained the rationale for this new type of factory building in his presidential speech to the *Troisième Congrès Du Béton de Ciment Armé* in January 1899.[127] Hennebique had initiated the conference topic by referring to two other manufacturing buildings near Lille. These were constructed around the same time as the Six building, but for the Frings and Barrois Frères local family businesses; and like the Six wool-combing mill in Tourcoing these have also, sadly, since been demolished. There was a growing need of building commissioners in the north of France for large, multi-storeyed manufacturing structures with expansive fenestration; this allowed in as much daylight as possible for a Northern European climate, particularly under the grey winter skies. Maximum light was particularly important in textile manufacturing, and within that

[127] François Hennebique, 'Troisième Congrès Du Béton de Ciment Armé. Séance Du Mardi Soir 24 Janvier 1899. Suite.', *Le Béton Armé* 1, no. 12 (May 1899): 6.

specifically the combing and spinning of delicate wool fibres to be used in the many weaving looms in the northern region of France – the workforce had to be continuously vigilant about the dangers of damage to the product during a largely automated process. Of course Hennebique was not operating in isolation, and would have been well aware of the use of extensive facade and roof glazing within metallic framing in, for example, the great Parisian department stores of the *Belle Époque*, as well as the ever-ascending Chicago skyscrapers. The other 'daylight factory' in the subsequent case study is the cocoa and sugar processing building, *La Cathédrale,* at the Menier Chocolate Factory (1908) in Noisiel-sur-Marne. *La Cathédrale* had a truly monolithic reinforced concrete skeleton. The extensive fenestration was the defining feature of the building (hence the derivation of its name), dictated by the building commissioner Henri Menier, with advice from his chief factory engineer as well as his French architect Stephen Sauvestre (1847-1919) and engineer Armand Considère. This was also intended to give the many planned daytime visitors an opportunity to appreciate the semi-automated and hygienic cocoa and sugar mixing process in all its naturally lit glory.

A related perspective on improved daylight admission is described in the case study in Chapter 5 of four buildings in a new urban design approach. These included: the extension to *Banque Brunner* in Brussels (1900) with its new banking hall that had a unique *béton armé* and glass *coupole* in its roof; the *Entrepôt Royal B* import warehouse also in Brussels (1906) which used metal and glass skylights for the internal courtyards; and the annex to the *Archives Départmentales du Nord* in Lille (1910), where surrounding existing walls to the enclosed site in the last building had removed the possibility of windows, but the similarity of approach (and system) to the *Entrepôt Royal B* import warehouse is striking, though on a significantly smaller scale. Both staff and clients could therefore benefit from more natural light while depositing and withdrawing valuable items, with the effectiveness of the glazed skylights still remarkable to this day. By contrast, for the street facade infill of the HBM at 7 rue de Trétaigne in Paris (completed in 1904, see the case study of HBMs in Chapter 3), glass bricks were initially considered by the architects to admit more natural light, but they were not used during construction – this was because of both their high initial cost, as well as their potential deterioration when exposed over time to direct sunlight, so adding to ongoing maintenance costs for what was intended to be affordable accommodation. Glass bricks had already been used to the rear of the private *immeuble* at 25b rue Benjamin Franklin, completed in Paris earlier in the same year (described fully in Chapter 6 on the application of the historical mechanism in the thesis).

Case study: 'daylight factories'

François Hennebique's original technical rationale for using his *béton armé* system in monolithic structures with highly glazed facades in the North of France is exemplified by the Charles Six wool-combing mill in Tourcoing near Lille (see later in this case study). The building incorporated an architecturally-pleasing, curved corner to its street facade, which was continuously glazed on the majority of floors. The ramifications of Hennebique's structural logic, explained earlier, were amplified in a reflection by Collins, who was commenting on the extensive use of continuous glazing during the later Interwar period, which he interpreted as being derived from new concepts of spatial integration:

> … the rapidity with which it assumed the character of dogma is something of a mystery, since it was frequently applied without much rational justification, and was merely seized upon by a small group of theorists as a kind act of faith. It seems likely to have originated in the design of Hennebique's early spinning mills, which were the models for so many industrial buildings of the first quarter of the century, the most notable being Bauhaus.[128]

Pevsner had started a brief section on the first concrete factories at the end of his major compendium on the history of building types, with a reference to the Six building that was derived from Collins' prior research, using one of Collins' photographs.[129] Banham subsequently explored more fully the architectural typology of the 'daylight factory' as he termed it, focusing on pre-First World War North American examples; his research was done without any direct reference to Collins, a contemporaneous architectural historian and compatriot.[130] There was only a brief nod, almost as an afterthought, to the potential technical connections with Hennebique.[131] Banham set out his own approach in the introduction to his work, when he noted how non-industrial buildings resembled industrial ones during the interwar years:

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[128] Collins, *Concrete. The Vision of a New Architecture*, 204. As previously noted in Chapter 1 under the description of the key industrial patents, Collins had suggested the possible use of Considere's *béton fretté* system in the first 'daylight factory' completed in 1902 for Kelly and Jones in Greenburg, Pennsylvania. This building had principally employed the Ransome reinforced concrete system – which provides another intriguing connection between France and North America.

[129] Nikolaus Pevsner, *A History of Building Types. The A.W. Mellon Lectures in the Fine Arts. Bollingen Series XXXV, 19.* (Princeton University Press, 1976), 288.

[130] Banham, *A Concrete Atlantis. US Industrial Building and European Modern Architecture.*

[131] Banham did make a nodding reference to Collins' prior work in the book version of his doctoral thesis (*Theory and Design in the First Machine Age*) published in 1959, though this was only in the general bibliography. That book had begun to lay out Banham's overall argument taken up with more fervour in

> [This] was construed, rather, as a promise that these buildings would be as functionally honest, structurally economical and, above all, as up-to-the-minute as any of the American factories that Le Corbusier hailed as "the first fruits of the New Age." The forms of factories and grain elevators were an available iconography, a language of forms, whereby promises could be made, adherence to the modernist credo could be asserted, and the way pointed to some kind of technological utopia.[132]

Banham was more direct than Collins before him in attributing the origins of the International Modernist interpretation of these factories. According to Banham, Le Corbusier (and others) had copied and edited from pre-First World War photographs of North American industrial prototypes, including silos and factories, and then used these pictures in postwar articles that were combined in his work *Vers une architecture* or *Towards a new architecture*, which was highly influential in assuring the ascendancy of an International Modernist architectural genre.[133] ‘Daylight factories’ were typified by Henry Ford’s vast and expanding Highland Park car factory built on the edges of Detroit from 1910 onwards (Figure 1.17). The design of this immense manufacturing complex was informed by novel Taylorist ideas about a more scientific or rational approach to industrial flow processes, including the provision of a more efficient working environment to meet rapidly rising production schedules.[134] Le Corbusier had not seen the ‘daylight factories’ in person as he had little interest, at least in this case, in an approach to design replication of carefully inspecting structures that inspire the new designer – instead he was trying to reinforce through these emblematic North American examples, a philosophical proposition about the key aesthetic contribution of engineered structures to a new form of modern architecture. Hence, later on, the main administration building of the Fagus industrial complex in Alfeld, Germany, completed in 1913, was singled out as a key derivative International Modernist structure by

Concrete Atlantis. It seems the two British architectural historians, born just a few years apart and both of whom had moved to North America for their research and teaching, had a ‘sibling rivalry’ of their own. See Kenneth Frampton’s foreword and Réjean Legault’s introduction to the second edition of *Concrete: The Vision of a New Architecture*, as well as Hinchcliffe’s piece on Collins. Curiously, Williams’ analysis of Banham’s life and works makes no mention of Collins. Collins, *Concrete. The Vision of a New Architecture*, xv–li; Tanis Hinchcliffe, ‘Peter Collins: The Voice from the Periphery’, in *Twentieth-Century Architecture and Its Histories*, ed. Louise Campbell (Society of Architectural Historians of Great Britain, 2000), 184–85; Richard J. Williams, *Reyner Banham Revisited* (Reaktion Books Ltd, 2021).

[132] Banham, *A Concrete Atlantis. US Industrial Building and European Modern Architecture.*, 7.

[133] Banham, 11–15, 18; Le Corbusier, *Towards a New Architecture* (London: J. Rodker, 1931).

[134] Biggs has the best technical coverage of Ford’s Highland Park factory in her Phd thesis and subsequent book. See: Biggs, *The Rational Factory. Architecture, Technology, and Work in America’s Age of Mass Production*, chap. 3; Biggs, ‘Industry’s Master Machine: Factory Planning and Design in the Age of Mass Production, 1900 to 1930’, 95–117.

Russell-Hitchcock and Johnson in their guide to the pivotal 1932 North American exhibition on 'The International Style: Architecture since 1922' and reinforced by Pevsner subsequently, who declared that it "started the International Modern with its beautifully proportioned glass wall."[135]

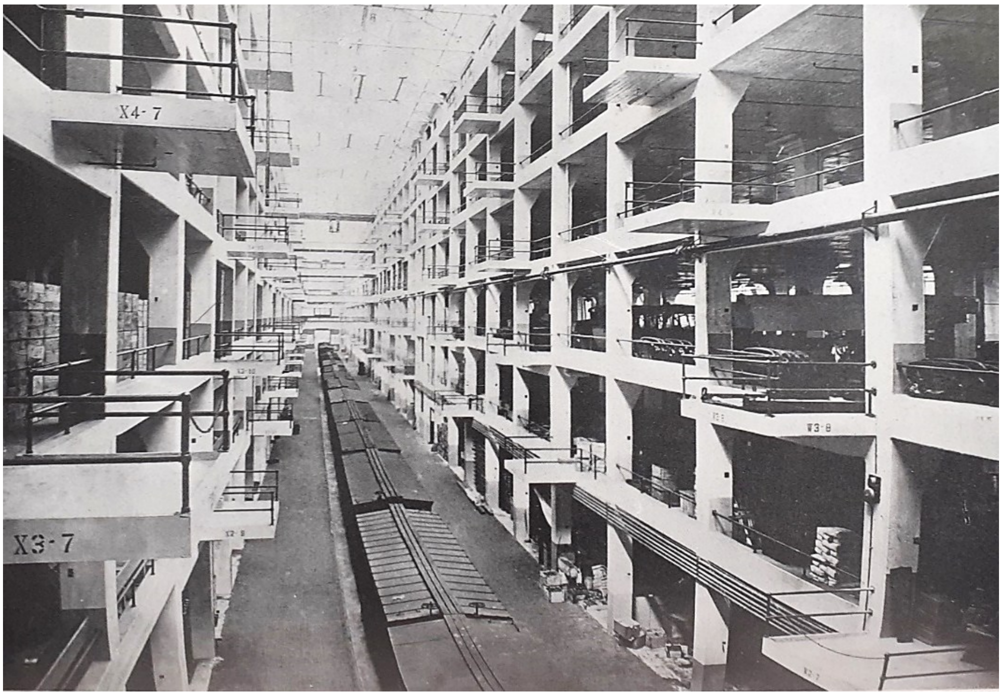

Figure 1.17: Interior of Ford's vast new Highland Park factory car assembly building outside Detroit (Kahn, 1910 on) in 1915 with its cantilevered galleries and skylights reminiscent of certain historic examples in this thesis. (The American Architect, Vol. CVII, No. 2044, 1915, plates)

The Fagus factory had been designed by the young German architect partnership of Walter Gropius and Adolf Meyer (1881-1929), the former subsequently achieving worldwide fame as the man who established the interwar *Bauhaus* movement as a leading sub-genre of International Modernist architecture.[136] The commissioner of the expanded shoe-last manufacturing complex in Alfeld had wanted to recreate his main client's American shoe factory; however, in the case of the administration building at least, this would be *without* using a monolithic reinforced concrete or cement structure but instead more traditional construction materials of brick and timber sat on concrete foundations – it was the glazed corner staircase atriums at each end of the structure that became iconic features of International Modernism, even thought they echoed the precedent set by the Six wool-combing mill in Tourcoing more than a decade before, arguably more elegantly

[135] Henry-Russell Hitchcock and Philip Johnson, *The International Style*, 2nd ed. (W.W. Norton & Company, Inc., 1995), 44–45; Pevsner, *A History of Building Types. The A.W. Mellon Lectures in the Fine Arts. Bollingen Series XXXV, 19.*, 288.
[136] Carsten Krohn, *Walter Gropius Buildings and Projects* (Birkhauser Verlag GmbH, 2019), 9–10, 28–33.

with its curve. Gropius may not have seen the original North American factory on which the Fagus complex was modelled – he and Meyer were brought in after initial designs were started by another architect, and we do not know precisely when Gropius first visited the United States, before he emigrated there permanently in the 1930s.

Biggs and Slaton were singled out in the historiographic review for their SCOT approach to a history of technology about 'rational' factories, from which the research methodology is partially derived.[137] A Masters thesis by Mortensen investigated three extant American 'daylight factories' in Dayton, Ohio with an interest in their preservation and eventual renovation, while a conference paper by Leatt examined interwar 'daylight factories' in Britain, focusing principally on Owen Williams (1890-1969) as a significant British reinforced concrete architect-engineer.[138] These derived from interwar buildings designed by Gropius, including the famous *Bauhaus* design training complex in Dessau (arguably industrial in at least one of its key purposes). The Fagus factory building and subsequent *Bauhaus* and other European interwar approaches further developed the mass use of glazing that had begun on a vast scale with London's Crystal Palace of the 1851 Great Exhibition, and was subsequently used by the British for their enormous railway station sheds; and then the French during the first stage of the metallic building design revolution that is described in Chapter 5.[139]

Many such smaller-scale industrial buildings, when compared to Ford's Highland Park complex, were constructed in Europe before the First World War. One of the most notable ones was Peter Behrens' (1868-

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[137] Biggs, 'Industry's Master Machine: Factory Planning and Design in the Age of Mass Production, 1900 to 1930'; Biggs, *The Rational Factory. Architecture, Technology, and Work in America's Age of Mass Production*; Slaton, 'Origins of a Modern Form: The Reinforced-Concrete Factory Building in America, 1900-1930'; Slaton, *Reinforced Concrete and the Modernization of American Building, 1900–1930*.

[138] Jennifer L. Mortensen, 'Reclaiming the Daylight Factory: The Significance of Versatility in the Preservation of Early Twentieth Century Concrete Frame Industrial Buildings in Dayton, Ohio' (University of Washington, 2015); Samuel Leatt, 'Owen Williams's Boots' "Wets" Factory - a Case Study on the Daylight Factory Typology', in *Studies in the History of Services and Construction, Proceedings of the Fifth Conference of the Construction History Society,* ed. James W.P. Campbell et al. (Construction History Society, 2018), 129–40.

[139] Other researchers have studied early North American 'rational' factories and particularly Albert Kahn (1869-1942), the lead architect of Henry Ford's Highland Park factory. See Grant Hildebrand, *Designing for Industry. The Architecture of Albert Kahn.* (The MIT Press, 1974); Terry Smith, 'Architecture and Mass Production: The Functionalism Question', in *Making the Modern. Industry, Art and Design in America.* (University of Chicago Press, 1993); Terry Smith, 'Albert Kahn: High Modernism and Actual Functionalism', in *Albert Kahn, Inspiration for the Modern*, ed. Brian Carter (University of Michigan Museum of Art, 2001); Charles Hyde, 'Assembly-Line Architecture: Albert Kahn and the Evolution of the U.S. Auto Factory, 1905-1940', *IA, The Journal of the Society for Industrial Archaeology* 22, no. 2 (1996): 5–24; Federico Bucci, *Albert Kahn: Architect of Ford* (Princeton Architectural Press, 2002); Juergen Reichardt, 'Construction', in *Albert Kahn's Industrial Architecture. Form Follows Performance*, ed. Thorsten Buerklin and Jurgen Reichardt (Birkhaeuser, 2019).

1940) AEG Turbine Manufacturing Hall in Berlin completed in 1909, just before the Fagus Factory, employing reinforced concrete within a mainly steel structure in a novel architectural approach; Gropius had worked for Behrens prior to starting up in partnership with Meyer.[140] A lesser known example, also in Germany and without *any* concrete or brick, is the Steiff enterprise manufacturing building in Giengen completed in metal and glass in 1903.[141] All of this led ultimately to glazed curtain walls that were completely separate from a building's skeleton, employed at *les grands magasins Decré* in Nantes by Henri Sauvage in 1931, in which direction the first Chicago skyscrapers had always been pointing.[142]

The influence of North American 'daylight factories' on International Modernist architecture derived at least in part from French textile manufacturer needs converted into structural requirements, specifically connected to admitting more natural light, and was subsequently developed into what we would now call an architectural trope. Banham had attempted in his book to resurrect a counter-spirit of early twentieth-century construction innovation, embodied in the original buildings when they were first designed and built in North America during a peak period of construction from 1905 to 1914 – he duly acknowledged postmodernist architects Robert Venturi (1925-2018) and Denise Scott Brown for preceding him with their thought-provoking book 'Learning from Las Vegas', intended as a further critique of the International Modernist trope.[143] In summary, there was a cross-Atlantic building design exchange that not only changed direction a number of times, but also changed meaning in the process.

Returning therefore to France, the small-scale 'daylight factory' that was the Charles Six wool-combing mill in Tourcoing near Lille used the *béton armé* system for its design and construction between 1895-7, this building clearly pre-dated the emergence of the 'daylight factory' architectural typology (see Figures 1.18 (a) and (b)). Its novel monolithic approach to the structure allowed the proprietor to run his textile manufacturing

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[140] Hub, Berthold, 'Architect versus Engineer: Monumentality versus Dematerialization', in *Before Steel. The Introduction of Structural Iron and Its Consequences* (Sulgen/Zurich: Verlag Niggli AG, 2010), 159–72; Krohn, *Walter Gropius Buildings and Projects*.
[141] Blanca Lleo, 'Steiff Factory, 1903. The Story of a Pioneer.', *RA Architecture* 22 (2020): 236–41.
[142] Traisnel, 'Le Métal et Le Verre Dans l'architecture En France. Du Mur à La Façade Legère.', 385–87; Thomas Leslie, '"As Large as the Situation of the Columns Would Allow." Building Cladding and Plate Glass in the Chicago Skyscraper, 1885-1905', *Technology and Culture* 49 (April 2008): 399–419.
[143] Banham, *A Concrete Atlantis. US Industrial Building and European Modern Architecture.*; Robert Venturi, Denise Scott Brown, and Steven Izenour, *Learning from Las Vegas* (The MIT Press, 1972).

operations in a maximum amount of natural (as opposed to artificial) light – through the large glazed windows that took up the whole of the infills on all sides of the building above ground floor level.

Figures 1.18 (a) and (b): Undated photographs of a facade with curved corner (above) and upper floors and roof terracing (below) of the early 'daylight factory' that was the Charles Six wool-combing mill, Tourcoing (architect unknown, 1897). (Peter Collins Fonds, John Bland Canadian Architecture Collection, McGill University Library)

François Hennebique first mentioned the building in a speech to one of his annual congresses for agents and others with an interest in his *béton armé* system, alluding to the enduring French Rationalist position espoused by followers of Viollet-le-Duc:

> Here is another application of the system. We did a few in the last year. You can see how little space is taken up. We return to the mullions of our old Gothic churches; these uprights which are 0.50 x 0.30m thick support the entire construction, the rest is only filling.[144]

Hennebique's reference to 'a few in the last year' is to at least two other buildings near Lille. The accompanying photograph that Hennebique used in his talk (Figure 1.19) shows the incomplete wool-combing mill, one assumes in late 1896, when it was supposed to have been finished according to the original agreement with Charles Six, the factory proprietor.

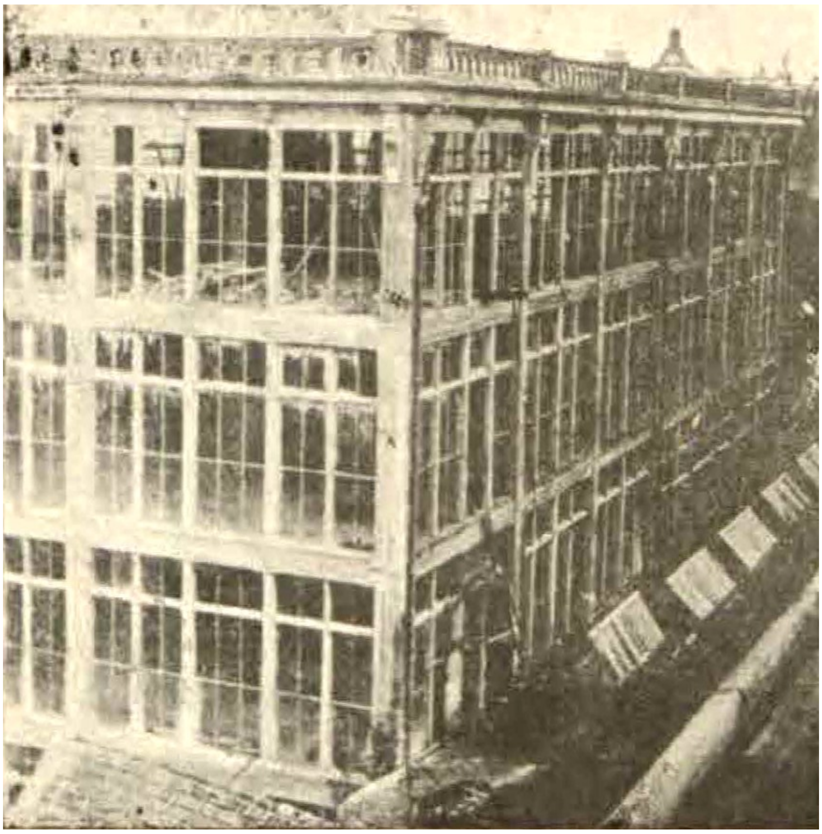

Figure 1.19: The Charles Six wool-combing mill, Tourcoing (architect unknown, 1897), during construction, no date. (Le Béton Armé 1899, 12, plates)

Chapter 4 looks at the acrimonious correspondence between the unhappy building commissioner and the local Hennebique contractor Debosque-Bonte, about the former's continual discontent with construction delays and what he claimed to be poor on-site workmanship. Debosque-Bonte was a Hennebique *concessionnaire*

[144] Hennebique, 'Troisième Congrès Du Béton de Ciment Armé. Séance Du Mardi Soir 24 Janvier 1899. Suite.', 7. « Filature Six à Tourcoing. 16. Voici l'application du même système. Nous en avons fait la dernière année quelques-unes. Vous voyez combien les montants tiennent peu de place. Nous en revenons au meneaux de nos vielles églises gothiques; ces montants qui ont 0.50 x 0.30m d'épaisseur supportent la construction entière, le reste n'est que remplissage. »

from Armentières, located within modern Lille Metropole, and is first recorded in the French construction press as having had a bid accepted in July 1887 to build two schools and a house at Pont-de-Nieppe, a hamlet just to the north of Armentières where he was based.[145] Delhumeau mentions the contractor in connection with buildings in northern France, noting that Debosque-Bonte was one of Hennebique's first *concessionnaires*.[146] Figure 1.20 shows an original illustration of the finished building as found in the *Centre d'archives d'architecture contemporaine* in Paris (76 IFA 276) – a reproduction of this water-colour picture was published in a 1902 edition of the *Béton Armé* and so was presumably produced five years after the building's completion.

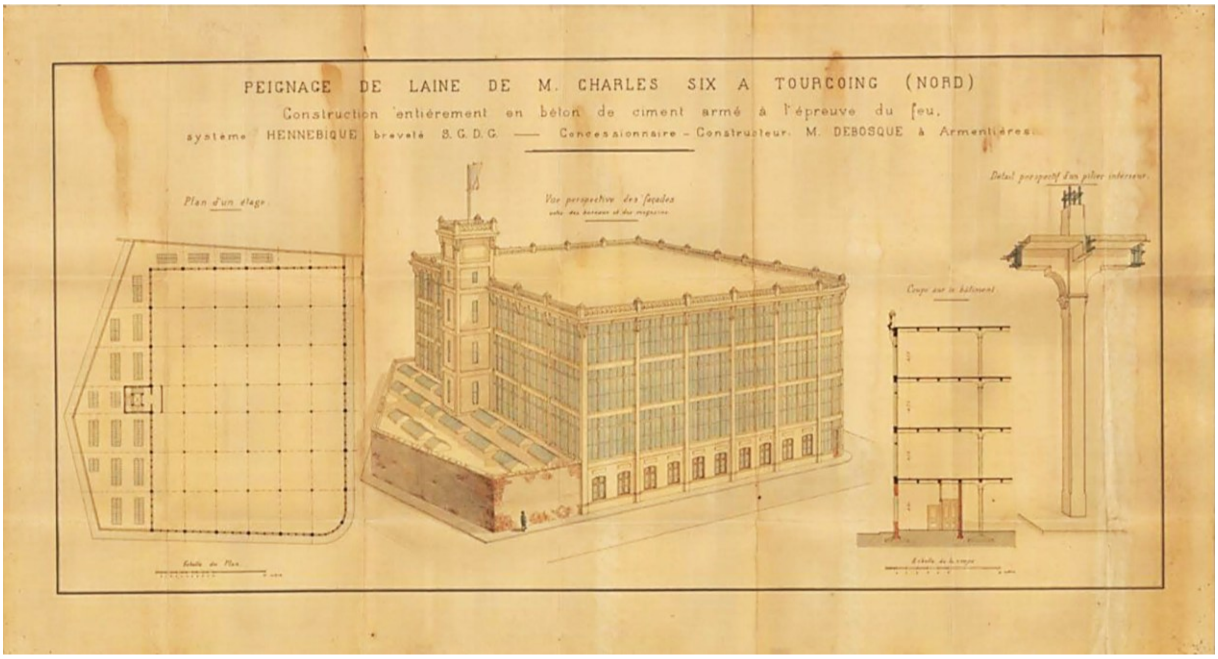

Figure 1.20: Illustration of the finished Charles Six wool-combing mill, Tourcoing (architect unknown, 1897), c. 1902 with a plan showing the column layout, a section showing the béton armé system flooring and a detail of a column-beam-slab connection. (76 IFA 276. CNAM/SIAF/Cité de l'architecture et du patrimoine/Archives d'architecture contemporaine)

The commentary that went with the *Béton Armé* illustration was mainly about Debosque-Bonte as Hennebique's main *concessionnaire* in the north of France (noting he had started with 8 projects in 1893 and expanded to 60 projects by 1901), who was an exhibitor at the Lille international industrial exhibition of that year. It specifically mentioned the impact of the wool-combing mill's novel structure on the admittance of more natural light into its interior:

[145] 'Resultats Des Adjudications', *La Semaine Des Constructeurs* 2, no. 6 (August 1887).
[146] Delhumeau, *L'invention Du Béton Armé : Hennebique, 1890-1914*, 86–88, 94–95 and footnotes.

> [The building of] Mr. Charles Six in Tourcoing is particularly interesting given its importance. We represent it opposite. This construction is entirely made of *béton armé*. It has three floors covered with a roof-terrace. The lightness of the pillars made it possible to obtain the maximum internal light.[147]

This unique approach to the admittance of more daylight into the Six wool-combing mill was picked up overseas in the British journal *Ferroconcrete* in January 1915, expanding part of the illustration from the *Béton Armé*, not long after the outbreak of the First World War.[148] The report must have been based on a journalistic visit undertaken before the major European conflict had started, as Tourcoing would have been caught just behind the German front lines. The author noted that building was one of the largest Hennebique structures at that time, as well as commenting on thinness of the external columns between which sat only glazing for the top three floors:

> … the mill of M. Six is a building of considerable magnitude, including four floors and covered by a flat roof, the whole being of ferro-concrete. Thanks to the great strength and rigidity of the material, it was possible to construct the outer walls so that above first floor level they consist entirely of slender columns and lintels, the intervening panels being occupied by windows. Thus, a maximum amount of light is secured for manufacturing purposes.[149]

Peter Collins' analysis of the Six wool-combing mill from the 1950s stands out as one of few significant ones undertaken, which as already said was used by Pevsner subsequently. Cusack provided additional technical details about the building in her doctoral thesis on the history of the *béton armé* system in Britain. Cusack noted that it was Hennebique's first, entirely reinforced concrete framed mill building, measuring 187 feet long and 170' 6" wide, and the curved angle of a corner of the building (not mentioned by Collins, but seen clearly in the photographs he possessed of it). She also inferred from the original water-colour picture (Figure 1.19) that a "small detail of the interior construction, indicates a similar arrangement to that employed in Hennebique's early British buildings, including, 'cranked up' rods, (not patented until 1897)."[150] By 'cranked up'

[147] Paul Gallotti, 'Le Béton Armé a l'Exposition de Lille', *Le Béton Armé* 5, no. 53 (1902): 78. « M. Charles Six à Tourcoing, est particulièrement intéressant par son importance. Nous le représentons ci-contre. Cette construction est entièrement en béton armé. Elle comporte 3 étages recouverts d'une terrasse. La légèreté des trumeaux a permis d'obtenir le maximum de clarté. »
[148] 'Ferro-Concrete at the Front', *Ferroconcrete* 6, no. 7 (1915): 249–50.
[149] 'Ferro-Concrete at the Front', 250.
[150] Cusack, 'Reinforced Concrete in Britain: 1897-1908', 110.

rods Cusack was referring to bent-up rebars and implying that features of Hennebique's subsequent 1897 patent were already present in Charles Six's wool-combing mill – we will come to the implications of these bent-up rebars later.

In commenting more generally about the application of the *béton armé* system in this building, Collins had placed Charles Six's wool-combing mill in the same industrial category as the earlier St. Ouen refinery in Paris completed in 1895, as well as the more contemporaneous Barrois Frères spinning mill at Fives in Lille. Collins had then discounted the Paris building because, while it was completed first, in his view it did not set the same architectural standard as the other two industrial examples he used. He therefore connected the textile mill buildings of the Barrois Frères' and Charles Six directly to later non-industrial buildings, because they established what he saw as aesthetic precedents related to the use of reinforced concrete in building design:

> Thus was created the idea of a visible reinforced concrete frame, expressed without embarrassment on the face of a building, and creating an entirely new scale of proportions both as regards the unaccustomed slenderness of the supports themselves, and the shapes of the voids created by the wider spans. It was some years before architects became familiar with these new forms, and when they did, the more enthusiastic of them saw in this use of glass a novel and exciting mode of expression, to be applied not only to factories, but to buildings of many other types and requirements.[151]

Collins made explicit comparisons between Charles Six's wool-combing mill and Ransome's first American 'daylight factory' in Pennsylvania, sadly also since demolished. He did this both directly, in a general statement about Ransome, as well as tangentially, by comparing both structures to the later Perret brothers' motorcar garage on 5 rue de Ponthieu in Paris (1907), which he saw as a true architectural breakthrough for reinforced concrete systems:

> These were both honest, straightforward constructions, but their designers never pretended that they were anything more than works of pure engineering. Of the two, the Hennebique factory is by far the

[151] Collins, *Concrete. The Vision of a New Architecture*, 68.

> more distinctive, both as regards the proportions of the openings, and the elegant way in which the columns are made to project in front of the beams.[152]

How does the unique approach taken in this wool-combing mill relate to the updated Hennebique patent of 1897, lodged in the year of the building's completion and considered in Chapter 1? Assuming that Cusack's earlier statement about the use of bent-up rebars is correct and given that Louis-Charles Boileau had already identified this novel component of the developing *béton armé* system by at least late 1895, it is possible that Hennebique had been testing out improvements to his materials-system on Charles Six and other such building commissioners in the North of France. Such an approach might well have contributed to frustrations about the construction process aired by the Tourcoing factory owner in irate letters to Debosque-Bonte, the local Hennebique contractor (see Chapter 4); the latter may as a result have been caught between the building commissioner's needs and efforts by the inventor of the *béton armé* system to both convert these needs into structural requirements *and* to improve his own innovation. The major changes to the emerging *béton armé* system beams since the original 1892-3 Hennebique French and Belgian patents described in Chapter 1, was the addition of extra (inverted) stirrups as well as bent-up rebars with fish-tail endings. All of this was aimed at making the combined and now truly monolithic building framing and floors more robust in resisting a range of additional forces produced by live loading – in the Charles Six wool-combing mill this would have included a large amount of heavy, vibrating wool-combing machines and the belt-drive mechanism that powered them. Files held at the *Archives Départementales du Nord* (M4178309) include an undated plan and elevations of the Six factory site probably from the 1980s, prior to the gradual demolition of significant buildings including the wool-combing mill, whose unique shape with one curved corner still stands out (see Figure 1.21).

[152] Collins, 185–86. Notwithstanding Collins' justifiable assertion about the garage at 5 rue de Ponthieu, which was demolished in the 1970s, and the fact that he devoted a number of pages to it in his major work on Auguste Perret, the building isn't included in this thesis as a historic example building. Some original Hennebique design plans and an elevation are available at the CAAC. By contrast, the historical mechanism described in Chapter 6 *is* applied to the *immeuble* at 25b rue Benjamin Franklin (1904) in Paris and also by the Perret brothers.

Figure 1.21: Plan, section and elevation of the Charles Six factory site, Tourcoing (architect unknown, 1897) in the 1980s with outline (circled) of the original wool-combing mill, undated. (M4178309. Archives Départementales du Nord)

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The second example historic building in this case study of 'daylight factories' was *La Cathédrale*, an elegant cocoa and sugar processing building at the Menier Chocolate Factory, Noisiel-sur-Marne near Paris, completed in 1908 (Figure 1.22). The building is an example of how the 'daylight factory' architectural typology developed from novel textile manufacturing buildings employing reinforced concrete structures in what is now the modern Lille Metropole – this was in parallel with the North American, much larger-scale form of the typology. The historic chocolate factory was vacated recently by its owners Nestlé France, who had used it as their headquarters since the 1990s, and the local community is continuing to explore new uses for it. Chapters 1 and 4 illustrate the role of Henri Menier as the building's commissioner, both in terms of his concerns about a breach of François Hennebique's patent for reinforced concrete piling, as well as the broader business objectives of the building beyond its key industrial capabilities.

The pre-existing Menier factory cocoa mill was a famous 1872 iron-framed structure designed an constructed by the French architect-engineer pair of Jules Saulnier (1871-81) and Armand Moisant (1838-1906) (see also

Chapter 5); the latter had also been the engineer for the concurrently built *Bon Marché* iron-framed department store in Paris.[153]

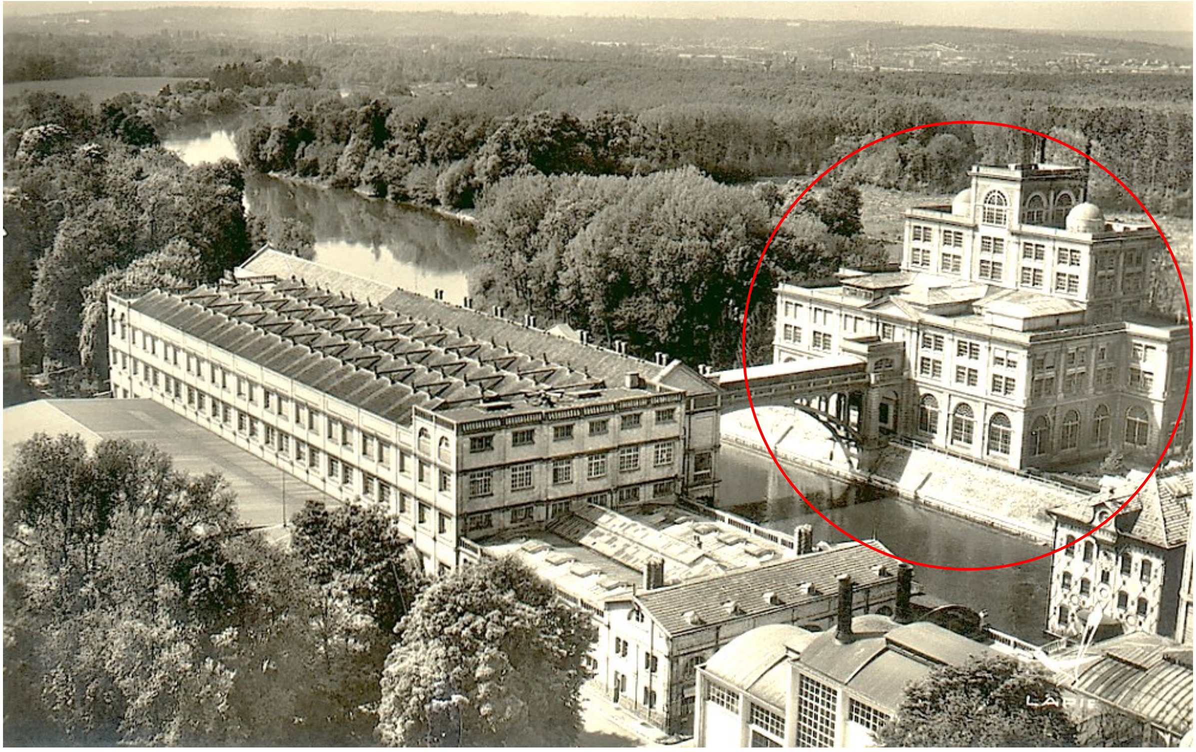

Figure 1.22: La Cathédrale cocoa and sugar combining mill (Sauvestre, 1908), circled to the right of photograph on the opposite bank to the main factory complex of the Menier Chocolate Factory, 1950s. The original iron-framed cocoa mill of 1878 is seen to the bottom right.(© pictures Editions Lapie – collection Ville de Noisiel)

The most comprehensive work that covers the history of the Menier Chocolate Factory at Nosiel-sur-Marne was published by the French *Service régional de l'Inventaire général des momuments et des richesses artistiques de la France*, at the time of the whole factory's renovation by French architects Reichen & Robert for the owners Nestlé France.[154] We are told why the new processing building was located on islands in the middle of the River Marne, because this was near both the original mill where the cocoa paste was made and near the building in which the finished chocolate was poured into moulds. The two islands were connected to each other with embankments and the unstable ground beneath them was reinforced with twelve-metre long *béton fretté* piles steam-hammered into the river (Figure 1.23).[155]

[153] Frances Steiner, *French Iron Architecture. Studies in the Fine Arts: Architecture, No.3.*, vol. 3 (UMI Research Press, 1984), 59, 110.
[154] Claudine Cartier, Helene Jantzen, and Richard Michel, *Noisiel, La Chocolaterie Menier Seine-et-Marne*, 3rd ed. (Inventaire général, SPADEM, 1994).
[155] Cartier, Jantzen, and Michel, 38–39.

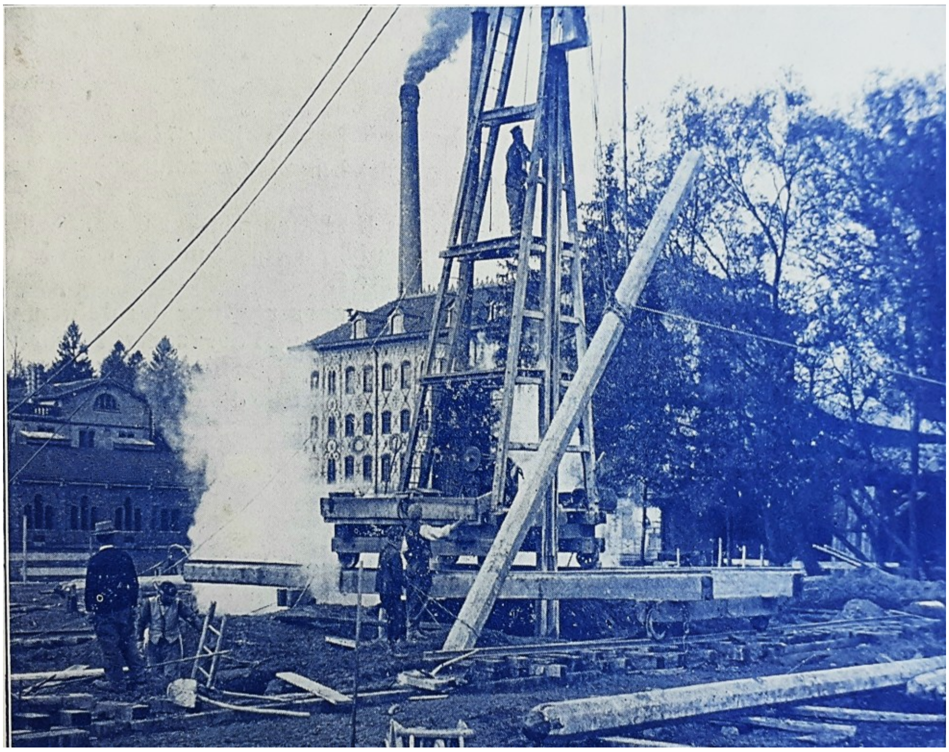

Figure 1.23: Steam-hammering a béton fretté foundation pile at the Menier Chocolate Factory, n.d. . (076 Ifa 1059/21. CNAM/SIAF/Cité de l'architecture et du patrimoine/Archives d'architecture contemporaine)

The architect for the new building was Stephen Sauvestre, who had previously added architectural panache to the original technical designs for the Eiffel Tower. *La Cathédrale* used Considère's *béton fretté* system for the building framing together with a reinforced concrete slab system for the floors that had been developed by an engineer called Viennot, about whom we know little – together these materials-systems produced a monolithic structure with large windows (Figure 1.24 (a)). The contractor was Jules Loup, who was familiar with Considère's *béton fretté* system having worked on other projects with him and Viennot. Together Sauvestre and Considère designed and built an arch-supported reinforced concrete *passerelle* or footbridge of almost 50m in length across the River Marne from *La Cathédrale* to the rest of the factory complex (Figure 1.24 (b)).

Figures 1.24 (a) and (b): Photographs taken during construction of La Cathédrale (Sauvestre, 1908) (top) and the passerelle connecting it to the rest of the factory complex (bottom), showing the scaffolding system for the Considère and Viennot reinforced concrete systems, c. 1906-8. (both © anonymous pictures – collection Ville de Noisiel)

Two initial design projects preceded the final design and construction of the *passerelle* connecting the building to the packaging complex across the Marne: the first, by François Hennebique, proposed a *béton armé* system bridge supported in the centre of the Marne; the second by Gustave Eiffel (1832-1923), provided for an all-metal footbridge. The Eiffel project was adapted by Considère and Sauvestre using the former's *béton fretté* system.[156]

A significant amount of natural light entered the building through its large windows, particularly on the ground and mezzanine floors where the mixing machinery was located. This not only contributed to efficient

[156] Cartier, Jantzen, and Michel, 42.

manufacturing operations, but the Menier business was also keen to admit visitors into the structure to witness their latest chocolate-making technology in action from the safety of a special public gallery at mezzanine level. *La Cathédrale* was completed eleven years after the Six wool-combing mill (1897) and a number of years before design work started on the Fagus factory in Alfeld, Germany. It would seem to have met similar structural requirements as a North American 'daylight factory' on eight floors, though on a much smaller plot size. An impression of thoroughly hygienic production would also not have gone amiss for those visitors who it was hoped would help promote a safe and tasty product to the world markets served by the business. We also know that the eight-storey, 9,177m^2 building was designed to house two symmetrical production lines, each including large mixing machines, with the central part reserved for freight and personnel elevators to reach all floors; the fluid cocoa paste was channeled to *La Cathédrale* in underground pipes from the original mill building.[157] The elegant interior of the new building partially hid its true function, with a 1914 visitor describing it as follows:

> … after descending a few stone steps of a wide staircase, one suddenly finds oneself in a spacious peristyle whose walls, vault, pavement and pillars suggest that it is not in a factory that one is but in the majestic foyer of some opera house. The elegant moldings of the pillars and the walls complete the impression.[158]

Both the *Pelnard, Considère et Caquot* files at the ANMT in Roubaix and the *Archives du Mairie de Noisiel-sur-Marne* contain many design drawings, photos and items of correspondence about the construction of *La Cathédrale*. Two sections of the structure, one of the *Avants-Corps Façade* (27 Septembre 1906, ANMT 1994 035 0191) and the other of a *Détail d'une travée des façades principales postérieures* (undated, ANMT 1994 035 0191) both indicate mapping of the *béton fretté* system building framing to the architect Sauvestre's original design shown in a *Serelevation de la Partie Centrale* (7 December 1906, ANMT 1994 035 0191). In the *Archives du Mairie de Noisiel-sur-Marne*, the same applies to a mapping between the architect's plan of the

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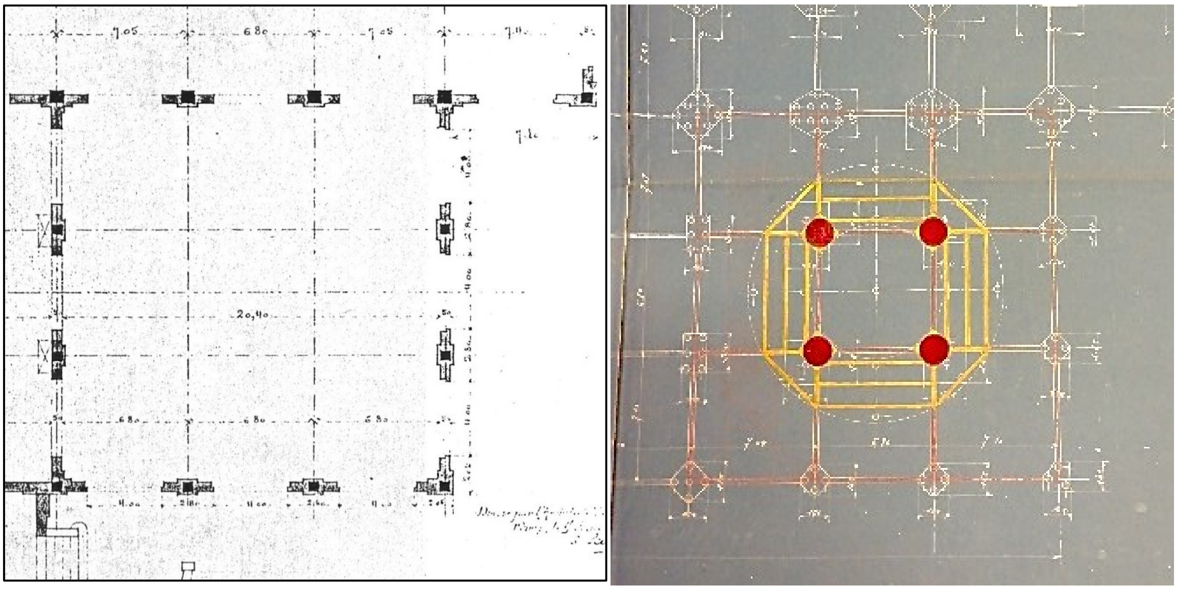
[157] Cartier, Jantzen, and Michel, 40–41.

[158] Cartier, Jantzen, and Michel, 43. « … après avoir descendu quelques marches de pierre d'un large escalier, on se trouve soudain dans un spacieux péristyle dont les murs, la voûte, le dallage et les piliers donnent à penser que ce n'est point dans une usine qu'on est mais dans le majestueux foyer de quelque opéra. Les élégantes moulures des piliers et les murs complètent l'impression.»

building and Considère's plans for the *béton fretté* system foundation piles and pillars (undated and unclassified, Figures 1.25 (a) and (b)).



Figures 1.25 (a) and (b): Original plan of part of the machine hall at La Cathédrale (1908) by Sauvestre (left) and corresponding structural plan by Considère for the foundations (right), with placement of one of the cocoa and sugar combining machines highlighted in red and yellow. (both © Nestlé France – Fonds Menier)

There are also original files on *La Cathédrale* and its *passerelle* in the Hennebique archives at the CAAC, confirming that the company was involved in provisional designs for both structures. A letter of 15 July 1905 from Louis Bourdenave, the engineer for the Menier Chocolate Factory, to Louis Roquerbe one of Hennebique's main *concessionnaires*, outlined the essential specifications for a proposed new mill (076 Ifa 1059/21). The letter contained a rough plan and as well as a sketch by the engineer of a structural section of the building (Figure 1.26 (a)), which they were planning to construct with a steel frame and vaulted roofing; though he noted that he was seeking advice on the use of the *béton armé* system for both economy and its ability to produce a truly monolithic structure. The same files also contain similar plans and a section of the proposed structure by Hennebique's central design office date 7 August 1905, which had reverted to terraced roofing (Figure 1.26 (b)).

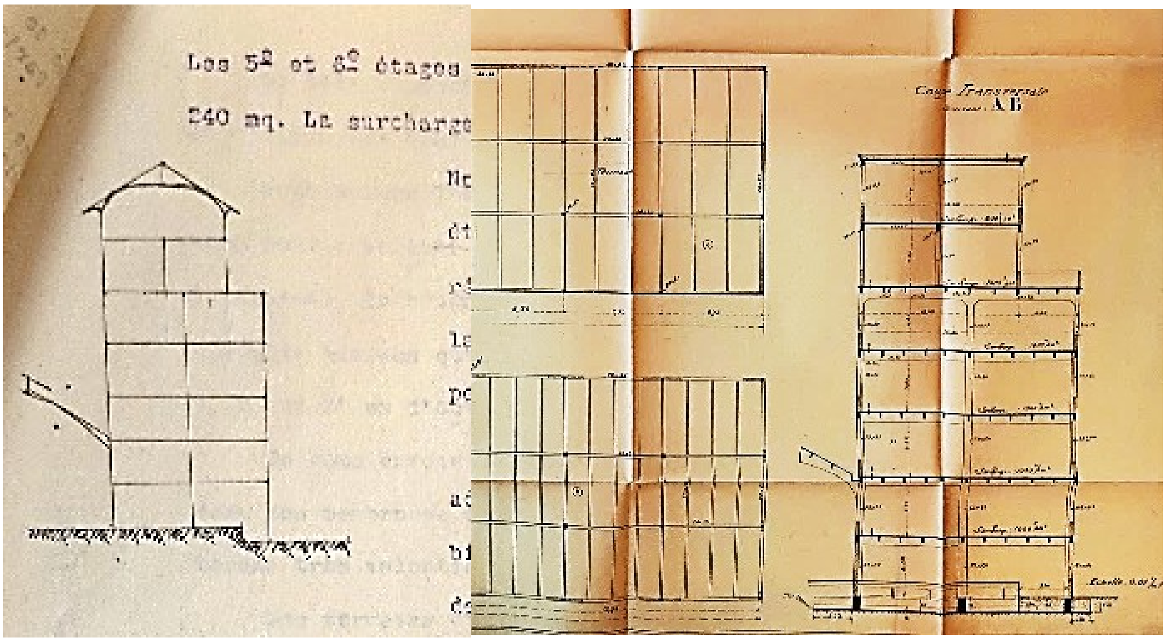


Figure 1.26 (a) and (b): Letter from Bourdenave to Roquerbe with sketch of proposed new mill section (left) and same section of the building by Hennebique's design office (right), Menier Chocolate Factory, Noisiel-sur-Marne, 1905. (076 Ifa 1059/21. CNAM/SIAF/Cité de l'architecture et du patrimoine/Archives d'architecture contemporaine)

Due perhaps to committing to a lower overall cost or being known better by the architect, the construction of *La Cathédrale* was undertaken by Loup as the contractor using the *béton fretté* and Viennot systems, with which he was most closely associated. This may well have contributed to the acrimonious exchanges between Hennebique and Menier/Considère beginning in early 1906 and described in the examination of patent disputes in Chapter 1, which eventually led to a protracted breach-of-patent dispute in the French courts. It seems to be a similar story to the planned use of the *béton armé* system for the new wool-conditioning complex in Roubaix completed in 1901, which was replaced by the Coularou system because the chosen contractor, presumably on price, acted as the local agent for that business (see the case study in Chapter 5 of four buildings in a new urban design approach).

2e. Street decor as a structural requirement

The historic example buildings in the case studies in this thesis used different approaches to cladding and decoration of their street facades. These ranged from polychrome bricks and glazed tiling at the wool-conditioning complex in Roubaix near Lille (1900 – see the case study of four buildings in a new urban design approach in Chapter 5), glazed ceramic stoneware at the *immeuble* at 3 rue Claude-Chahu and geometric glazed tiling at the *immeuble* at 185 rue Belliard both in Paris (1903 and 1913 – see the case study of Parisian immeubles with decorative ceramic facade cladding in Chapter 5), and polychrome bricks combined with glazed tiling at the HBM complex at rue de la Saïda in Paris (1914 – see the case study of HBMs in Chapter 3). The HBM at 7 rue de Trétaigne in Paris (1904 – see the case study of HBMs in Chapter 3) employed a clay brick exterior wall infill within the load-bearing, reinforced concrete structure; this was all covered for weather protection by white limewash, producing a unique plain effect that may have had wider architectural ramifications. By contrast the *immeuble* at 1 rue Danton in Paris (1900 – see the case study of the building in Chapter 4) and the HBM at 32 rue Marconi in Brussels (1902 – see the case study of HBMs in Chapter 3) both used *béton de ciment* as a protective barrier for their facades; the former in an attempt at a traditional Parisian style, much critiqued, the latter in a more adventurous, and so perhaps more acceptable, genre of Eclecticism reminiscent of Ancient Egypt. Christophe noted that concrete could be used in moldings and reliefs and that the large variety in the color of cement produced "the perfect illusion of ashlar. To increase the weather resistance of concrete and improve its appearance, it can be sealed by a fluatuation or silication such as limestone, or covered with special coatings such as lithogen, stucatine, etc. , or simply oil paint."[159]

Christophe had also expressed his views on how cladding street facades could make reinforced concrete and cement skeletons more amenable to the many *Belle Époque* architects who disliked their visibility:

> It is enough to leave the reinforced concrete studs and sleepers visible, and to fill the gaps with brick or ceramic tile panels. This type of decoration, sincere and rational, is hardly found to this day except in industrial constructions. For higher-ranking buildings, many architects prefer to take advantage of the tonality of cement to imitate stone, when they do not hide the frame under a general cladding.[160]

Another Belgian engineer, Louis Cloquet, provided further commentary in a 1908 article in *Le Béton Armé*, when he admitted that the bareness of concrete surfaces did "not seem likely to arouse any aesthetic emotion", unliked the work of traditional craftsmen when using their expressive skills on building materials.[161] Subsequently, in the same year, a French architectural commentator, Charles Saunier, provided the views of

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[159] Christophe, *Le Béton Armé et Ses Applications*, 152. « … qui donne l'illusion parfaite de la pierre de taille. Pour augmenter la résistance du béton de ciment aux intempéries et améliorer son aspect, on peut le trailer par la fluatuation ou la silicatisation comme les pierres calcaires, ou le recouvrir d'enduits spéciaux tels que le lithogène, la stucatine, etc. , ou simplement de peinture à l'huile. »
[160] Christophe, 151. « II suffit de laisser apparents les montants et traverses en béton armé, et de garnir les intervalles de panneaux en briques ou en carreaux céramiques. Ce type de décoration, sincère et rationnel, ne se rencontre guère jusqu'a ce jour que dans les constructions industrielles. Pour les bâtiments de plus haut rang, beaucoup d'architectes préfèrent profiter de la tonalité du ciment pour imiter la pierre, quand ils ne dissimulent pas l'ossature sous un revêtement général. »
[161] Louis Cloquet, 'L'Emploi Du Béton Armé En Architecture', *Le Béton Armé* 11, no. 117 (1908): 22–23.

his own construction profession, which corrected Christophe's initial perception that architects might accept the idea of cement imitating stone on facades – this issue is considered in the case study in Chapter 4 of the Parisian *immeuble* at 1 rue Danton which took such an approach. Saunier certainly concurred that the use of cladding was essential for masking materials that were "poor in appearance" or "sad" such as reinforced concrete or cement. The novel materials-system could only be used within the polite urban setting if its neutral tone was enhanced by the decorative cladding.[162] Gillet provided additional Parisian context for innovative ceramic-based cladding used to hide novel reinforced concrete and cement systems. He noted the combination of a large reduction in the price of ceramic tiles at this time and an improvement in their frost resistance, meaning that they became "the material of choice for the exterior cladding of buildings, providing a protective shell for the structure within … The Parisian architects implemented this building technique in a brilliant manner and contributed significantly to the development of an architectural language that reached its golden age around 1910."[163]

Double wall systems also provided a means to fix stoneware cladding to the facade. The private *immeubles* at 3 rue Claude-Chahu (1903) and 185 rue Belliard (1913) (see the case study of Parisian buildings with decorative ceramic facade cladding in Chapter 5), used similar systems for dual-skin walls; these were originally developed to allow warmer and drier air to circulate within them in the cold and damp winter climate of the capital, but equally providing a cooling effect in the hotter months. Gillet refers to Cottancin's approach to this specialist walling system which was applied in a derived form by the French architect Henri-Louis Deneux (1874-1969) and his contractor Gustave Degaine (1866-1928) to the *immeuble* at 185 rue Belliard. The system consisted of an interior and exterior brick wall within which an insulating mass of air circulated. The exterior wall bricks were attached with metal filaments to the interior wall and if hollow bricks were used, then all the spaces inside the exterior wall were filled with a more fluid form of cement, though still leaving an air gap between the two skins. A further insulating layer of cork was also applied to the inside of the exterior wall.[164]

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[162] Charles Saunier, 'Nouvelles Applications Du Gres Flammé Au Revêtement Des Façades', *L'Architecte*, November 1908, 83.
[163] Valentin Gillet, 'An Iron-Mounted Stoneware Façade in Paris: Charles Klein's Apartment Building at Rue Claude-Chahu 9', in *Iron, Steel and Buildings: Studies in the History of Construction. The Proceedings of the Seventh Annual Conference of the Construction History Society*, ed. James W. P. Campbell et al. (Construction History Society, 2020), 129.
[164] Gillet, 'Conception et Confection. Une Histoire Matérielle Du Revêtement Céramique Des Immeubles Parisiens (1900-1914)', 125–26.

Chapter summary

The chapter included further technical details that were layered onto the framework of early industrial standards for the new reinforced concrete and cement systems covered in the first chapter. Clearly, there needed to be an economic justification for constructing new non-monumental, urban buildings and this was influenced in turn by varying (over time and location) local supply and demand factors – as still remains very much the case today. The family textile enterprises of Northern France were driven by the economics of operating a volatile business in a highly competitive international market; this spurred operational efficiency gains, in many cases connected to the quality of workforce and the state of the machine technology available. As François Hennebique had first explained to his conference delegates in 1899, supplemented by Collins' analysis in the 1950s, the Northern French textile manufacturers were seeking premises which allowed in more natural light, to meet increasing industrial prerogatives in a fiercely competitive expanding global market – this approach favoured the use of a *béton armé* system that could guarantee better structural efficiency for their factory buildings through monolithic approaches. These structures would use relatively less volume of construction material to support wider spans within the overall building framing, together with thinner slabs in the floors, requiring less load-bearing support and so fewer internal columns. The benefits from a more spacious design were exponential as the size of the building increased.

These drivers and efficiency gains linked to four key structural requirements using the novel reinforced concrete and cement systems which were most relevant to the complementary needs of commissioners of new buildings: fire resistance, structural efficiency, daylight admission and street decor. Increasing the structural requirement of manufacturing complexes for fire resistance could reduce insurance premiums and allow continuous production without major delays due to refitting facilities. The use of a novel materials-system had to be justified in a building design and execution project, and this could also be measured by its proven structural efficiency when compared to prevailing technology and methods, whether this was influenced predominantly by local or national factors. Moreover, the building framing, floors and foundations could be combined together into a truly monolithic skeleton by employing the novel materials-system – flat terrace roofing provided an additional space open to daylight at the top of a building. Another structural requirement derived from the novel materials-system was the admission of even more natural light into all spaces within the finished building. This was achieved through more and larger windows requiring thinner structural support, which supplemented new atriums with glazed-roofing as skylights or coupoles that had already accompanied the expansion of nineteenth-century metallic construction in monumental halls, markets, stations, banks and department stores. The same logic applied to other types of non-monumental, urban building, including large depositories, as well as within urban housing; in the latter case the *Art Nouveau* architectural genre of *Belle Époque* Eclecticism had encouraged winter gardens and daylit halls inside street houses. Such an approach to improved daylight admission was already happening in the late-nineteenth and early-twentieth century North American skyscrapers that had used predominantly steel, but would start to employ reinforced concrete and cement systems from 1903 onwards. This would become associated with a 'daylight factory' architectural typology that emerged during the later period of the *Belle Époque* and as shown in the case study in the chapter, may well have been derived from French historic example buildings within manufacturing premises. Importantly from the perspective of the prevailing *Belle Époque* eclectic approach to architecture, urban street facades could employ cladding behind which the novel materials-system, with its unappealing industrial connotations, might be both protected and hidden. The added bonus, as expressed by contemporaneous architects such as Charles Saunier, was that pleasingly moulded ceramic-based decorative features could be employed on such skeletons.

Section 1 summary

Section 1 provided details about the technical context of *Belle Époque* construction using the novel materials-system.

Chapter 1 defined and clarified the nature of industrial standards, focusing initially on how they have operated in engineering. After examining the importance of industrial innovation, the chapter concentrated on the *design* aspects of construction industry standards, referencing doctoral research on this by Angelino. The chapter also introduced three key components of early industrial standards for the novel materials-system: industrial patents for novel reinforced concrete and cement systems, structural specifications and technical guidance. Considerable details of the key innovative systems were provided, as well as consideration of the legal implications of industrial patents. The chapter then examined structural specifications including a case study of one of the first buildings to employ the *béton armé* system as patented by François Hennebique in 1892-3. The first voluntary technical guidance for the novel materials-system in a selection of European authorities was examined, and then the work and report of the French Commission on *ciment armé*, which produced national technical guidance for state-procured construction projects.

Chapter 2 covered building economics and key drivers associated with the business needs of building commissioners. It then described key structural requirements derived from specific commissioner needs. These included fire resistance, much appreciated by industrial commissioners in the North of France. Designing new non-monumental, urban buildings employing reinforced concrete and cement provided opportunities for structurally efficient approaches resulting from increasing monolithic combinations of building framing and floors (with foundations). The chapter also considered as a key structural requirement the admission of more daylight into buildings, connected to a 'daylight factory' architectural typology and subsequent International Modernist trope, which was illustrated in a case study of two example *Belle Époque* buildings completed on the outskirts of both Lille and Paris. The final key structural requirement captured new, decorative approaches to street decor, behind which the novel reinforced concrete or cement skeletons were both protected from water ingress and hidden from public view.

A schematic including the key information blocks in Section 1 is shown in Figure 1.27.

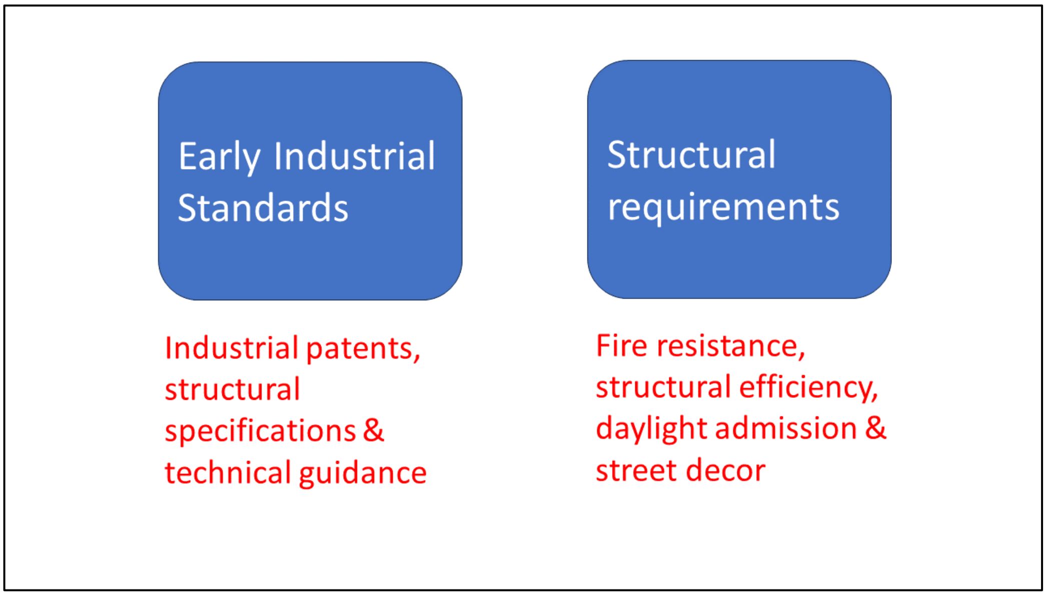

Figure 1.27: Schematic of the key information blocks and details for the technical context of Belle Époque construction using the novel materials-system

The schematic has, inevitably, much simpler components than the complexity of the modern-day relationships between technical standards and innovation:

1. Early industrial standards for the novel materials-system, including details of their key components: industrial patents, structural specifications and technical guidance.
2. Key structural requirements for innovative reinforced concrete and cement systems converted from building commissioner needs: fire resistance, structural efficiency, daylight admission and street decor.

The schematic answers the subsidiary research question posed at the start of Section 1, 'What were the key technical demands of the new reinforced concrete and cement systems and how did these manifest themselves within building design and construction during the period?', by presenting the two key information blocks for 'early industrial standards' and 'structural requirements' with their underlying details. As will be seen, these blocks provide essential components of a historical mechanism that helps answer the core research question.

Section 2. The societal context of *Belle Époque* construction using the novel materials-system

Section introduction

Section 2 describes the societal context of *Belle Époque* construction using the novel materials-system, in terms of those key actors with an interest in the process and outcomes of building design and construction during the period. In this way it sets a scene across two chapters about social motives for and regulatory pressures on building design and construction, as well as the roles of building commissioners and professionals. The section contains two case studies that, together with the remaining text, answer the subsidiary research question: 'How did the employment of new reinforced concrete and cement systems reflect societal expectations and in what ways did these manifest themselves within building design and construction during the period?'

Chapter 3 drills down into urban hygiene and social housing with a focus on Paris. The chapter describes the broader society within which the actors operated, which prioritised certain urban hygiene goals and espoused greater affordability of decent accommodation for the less privileged classes. Three historic examples of social housing, *Habitations à Bon Marché* (HBMs), illustrate these points in a case study.

Chapter 4 examines the specialist professionals who converted building commissioner needs into key structural requirements associated with the novel materials-system. The chapter describes how sibling rivalry *and* cooperation took place between architects and engineers, but also contractors. The regulatory pressures connected to urban construction, in particular the revised 1902 Paris municipal regulations for streets are also considered. There had been insufficient changes to the stricter Haussmannian rules they eventually replaced. The chapter concludes by considering the influence of these regulatory changes on *Belle Époque* building design using the novel materials-system, providing a case study of a historic building completed just before the revisions were introduced, which was the *immeuble* at 1 rue Danton in Paris completed in 1900 as the new headquarters of François Hennebique's expanding business empire.

The section ends with the key information blocks and details from both Sections 1 and 2, in the form of an expanded schematic that provides an answer to the subsidiary research question.

Chapter 3: Hygienic cities and social housing

Chapter 3 describes the growing importance of urban hygiene factors during the *Belle Époque*, connected as they were to over-crowding and the spread of contagious diseases. Various attempts to improve this situation are then examined, including efforts by Parisian architects and planners. The chapter considers the changing state of social housing, particularly in the French capital. The rationale for the construction of new social housing is described and a case study of three historic example HBMs in Brussels and Paris that employed reinforced concrete and cement systems illustrates the technical design response to social needs.

3a. Changing attitudes to urban hygiene

The urban population in France had grown from about 8 million in the mid-nineteenth century to around 17 million by 1914 – this was impressive, though not as extreme as Germany which reached an urban population of 29 million by the outbreak of WW1; more significantly, together with lower overall birth rates this saw a contrasting reduction in French rural population. Lille was still an important French city and regional centre during this period with 217,807 inhabitants in 1911, while Roubaix became a major textile centre near Lille that grew in population from 8,000 in 1801 to over 100,000 by 1886, placing it ninth in an overall French ranking, though Paris remained far ahead of all other cities with its 2.3 million inhabitants.[165] It seems that the French authorities were aware of the impact of urban overcrowding on the spread of epidemics at least as early as the 1830s. Ford notes that between 1804 and 1827 the population of Paris increased from 547,756 to 890,431 and population density per hectare rose from 159 in 1800 to 307 by 1846, but available housing was unable to keep up with this rapid growth, causing significant overcrowding in the French capital.[166]

The importance of hygiene to *Belle Époque* society became more apparent as the nineteenth century saw mass urbanisation linked to industrial expansion. These problems were worse in the French capital's poorer districts, resulting in high rents and numbers of cases of tuberculosis during the course of the nineteenth century. Even the Haussmann planning reforms of the 1850s and 1860s merely shifted the problem from the centre to the periphery of the capital. The French Third Republic saw a flourishing of intellectual activity including growing

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[165] Bullock and Read, *The Movement for Housing Reform in Germany and France 1840-1914*, 281; Marie-Joseph Lussien-Maisonneuve, 'Agrandir et Embellir Une Ville Industrielle (1851-1914)', in *Histoire de Lille. Du XIXe Siècle Au Seuil Du XXIe Siècle*, ed. Louis Trenard and Yves-Mairie Hilaire (Librairie Academique Perrin, 1999), 19.
[166] Caroline Ford, 'The Paris Housing Crisis and a Social Revolution in Domestic Architecture on the Eve of the First World War', *Journal of Modern History* 90 (September 2018): 581.

medical knowledge on how to combat typhoid, cholera and similar scourges which did not necessarily discriminate between the wealthy, the middle classes or the poor. The experts advocated methods centred around greater personal and communal hygiene, as well as increased access to more sunlight and fresh air circulation, particularly in the worst types of tenement housing for the working classes – unlike the members of the upper social echelons, they could not afford to move out of the over-crowded urban centres and locate themselves in houses or apartments on elegant new boulevards in leafy suburbs.

Bullock and Read point to the publication in France of Villerme's 1840 *Tableau de l'État Physique et Moral des Ouvriers dans les Manufactures de Coton, de Laine et de Soie*, followed closely by Chadwick's 1842 *Report on the Sanitary Conditions of the Labouring Population of Great Britain*, as transition points for public hygiene concerns in both countries.[167] The Second Empire saw the large-scale design in Paris of a coherent network of fresh water and sewers and an urban plan that was ordered into a circle crossed by many diametric sanitation lines. According to Chevalier in his extensive history of Parisian hygiene politics during the second half of the nineteenth century, the start of the Third Republic in 1870 corresponded with the new hygiene role of elected municipal councillors.[168] These 'hygiene actors' attacked not only poor domestic hygiene through sewer improvement and the removal of substandard housing, but they also pushed for the purification of the Seine and its tributaries through agricultural processes. The advent of a democratic age of hygiene in the French capital was pushed by a concern to prolong the life of all Parisians. One of these actors, the architect Émile Trélat (1821-1907), founder of the *École spéciale d'architecture* in 1865, played a key role in promoting public hygiene within his profession from the period of the Second Empire leading into the Third Republic. His theoretical advances were essential for improving the hygiene of daily life in an urban society and for producing healthier room heating systems, which in turn related to his desire to renovate teaching and architectural practices, a desire he shared with Eugène-Emmanuel Viollet-le-Duc and Anatole de Baudot:

> Frédéric Seitz posed the essential character of this link between the three men, which was manifested by the fact that these two faithful friends were integrated as tutors at the *École spéciale d'architecture*:

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[167] Bullock and Read, *The Movement for Housing Reform in Germany and France 1840-1914*, 3.
[168] Sebastien Chevalier, *Le Paris Moderne. Histoire Des Politiques d'Hygiène (1855-1898)* (Presses Universitaires de Rennes & Comité d'Histoire de la Ville de Paris, 2010), 296.

> Baudot, in 1865, for the course of Theory of Architecture whose chair was Trélat himself, and Viollet-le-Duc, in 1868, for the course of Comparative History of Architecture.[169]

Chevalier also pointed to the strong relationship between the rationalist school of architecture, questions of hygiene, and the important role that Trélat played in influencing the key decision-making networks. In a speech he gave to the Chamber of Deputies during its February 1895 sitting, Trélat opposed the proposed abolition of the Directorate of Civil Buildings, which in his view guaranteed high quality public architecture.[170] Ford singles out work by Paul Juillerat, head of the *Bureau de l'assainissement et du casier sanitaire des maisons de Paris*, who had shown that in certain less salubrious Parisian accommodation almost a tenth of the inhabitants died from tuberculosis.[171] In the previous year a *Casier sanitaire des immeubles parisiens* was established to record deaths by tuberculosis and other diseases linked to housing.[172] Ford connects Juillerat (and by implication Trélat before him) to Louis Bonnier (1856-1946), the Paris city architect who was pivotal in introducing updated street regulations in 1902 (see Chapter 4). They were co-authors of a report on the impact of tuberculosis in Paris, which according to them had contributed to over 100,000 mortalities in the decade 1894-1904; within it they also made a plea for architects to extend their professional skills to include hygiene issues, in contrast to the prevailing wisdom from Julien Guadet, professor at the EBA, who maintained that it was not for architects to delve into matters outside their core expertise.[173] That the dangers of the rapid spread of urban diseases were ever-present in the major conurbations of the world at this time, is highlighted in Merwood-Salisbury's description of New York tenement reform, including a reference to a 1900 exhibition organised by the Charity Organization Society of New York City. The exhibition included disease maps that were covered with black dots showing every case of tuberculosis that had been reported to the Board of

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[169] Chevalier, 303. « Frédéric Seitz a posé le caractère essentiel de ce lien entre les trois hommes, qui se manifesta par le fait que ces deux fidèles furent intégrés comme répétiteurs à l'École spéciale d'architecture: Baudot, en 1865, pour le cours de Théorie de l'architecture dont le professeur de chaire était Trélat lui-même, et Viollet-le-Duc, en 1868, pour le cours d'Histoire comparée de l' architecture. » See Frédéric Seitz, 'L'enseignement de l'architecture En France Au Xixe Siècle', *Les Cahiers Du Centre de Recherches Historiques*, no. 11 (October 1993). Trélat's ideas for circulated hot air contained in a sealed gap between the walls, rather than bringing dirt and infection inside habitable spaces, seem particularly relevant to modern ecological architecture.
[170] Chevalier, *Le Paris Moderne. Histoire Des Politiques d'Hygiène (1855-1898)*, 303.
[171] Ford, 'The Paris Housing Crisis and a Social Revolution in Domestic Architecture on the Eve of the First World War', 601.
[172] DHAAP/DAC, 'Les HBMs: Un Patrimoine Multiple (1894-1949)' (Mairie de Paris, 2019), 7.
[173] Ford, 'The Paris Housing Crisis and a Social Revolution in Domestic Architecture on the Eve of the First World War', 602 fn86.

Health within the previous five years, such that "nearly every building had at least one dot on it. Colored dots denoted the presence of typhoid, diphtheria and other diseases … these maps earned for New York City the 'title of the City of Living Death'."[174]

3b. Social housing

The first French social housing movement started in the small city of Mulhouse, connected with industrial philanthropy which was partially self-serving in keeping the workforce productive.[175] Urban population density increased with resultant overcrowding in the major cities, and concerns about the general welfare of the metropolitan masses started to emerge in the mid-nineteenth century. As previously described, a growing hygiene movement resulted in new stipulations for the amounts of natural light and ventilation required within streets and the internal and communal spaces of urban accommodation (see Chapter 4). Equally there was an expanding movement to provide more affordable housing for the worse off classes, even though during the *Belle Époque* the focus continued to be on construction for the better-off classes in the French capital. However, the years 1889 to 1901 saw the amount of Parisian apartments at lower rents increase as a total proportion of the total housing stock; by contrast, between 1891 and 1911 those dwellings with 'cheap' rents made up four fifths of demolitions, but only two thirds of new builds, resulting in a net depletion of stock. Apartments at the very lowest rent levels simply disappeared. Bullock and Read noted that a post-First World War influx of population from the countryside into cities, particularly Paris, created new suburban slums called *lotissements*, as landowners focused on rents from the revival of French industrial sites at the expense of a decent housing stock for the migrant workers needed to operate these very same sites. Those Parisians who did develop social accommodation at the start of the interwar years were limited to restricted plots and so forced to build narrow and upwards, unlike for example the more spacious garden cities of the London suburbs.[176]

The story of Parisian *Habitations à Bon Marché* (HBMs), urban housing blocks designed to provide hygienic and affordable accommodation in the capital for those designated in need, has been well documented by a range

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[174] Joanna Merwood-Salisbury, 'Architecture as Model and Standard: Modern Liberalism and Tenement House Reform in New York City at the Turn of the Twentieth Century', *Architectural Theory Review* 23, no. 3 (September 2019): 5.
[175] Ann-Louise Shapiro, 'Housing Reform in Paris: Social Space and Social Control', *Source: French Historical Studies* 12, no. 4 (1982): 491.
[176] Bullock and Read, *The Movement for Housing Reform in Germany and France 1840-1914*, 520.

of, mainly French, specialist researchers since the 1980s.[177] François Loyer considered HBMs as part of his much broader analysis of French nineteenth-century architecture undertaken during that starting decade. He saw them as the result of a challenge dating back to the beginning of that century:

> … reinforced concrete structures, brick construction; planning of urban islands, large open courtyards, planted areas; oblique perspectives, improved attics ... The architectural model of "hygienic housing" was defined; what was missing was a truly effective urban model. The principle of block town planning responded to this – expressing the abandonment of the traditional plot in favour of a global composition of neighbourhoods.[178]

Dumont's architectural history report for the French *Ministère de l'urbanisme et du logement* was subsequently expanded and published as a book.[179] Her research focus was very much on the role of the Rothschild Foundation in launching a highly prestigious 1905 design competition for HBMs, with more than 100 entries from a range of French architects; and the subsequent commissioning with an ambitious budget of a number of architecturally important HBMs in Paris. The competition was won by the talented young architect Augustin Rey (1864-1934). The novel principles behind his design were described in a contemporaneous international design journal article, which began by outlining the need to abolish inner courtyards and replace them with semi-public squares so that the air should circulate freely. The writer continued:

> M. Rey considers the staircase, which may be considered as an extension of the street, can and should be open to the outer air, and that this presents no inconvenience, because when people are on the

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[177] Marie-Jeanne Dumont, 'La Fondation Rothschild et Les Premières Habitations à Bon Marché de Paris, 1900-1925' (Ministère de l'urbanisme et du logement / Secrétariat de la recherche architecturale (SRA); Groupe histoire architecture mentalités urbaines (GHAMU), 1984); Marie-Jeanne Dumont, *Le Logement Social à Paris : 1850-1930. Les Habitations à Bon Marché* (Mardaga, 1991); Monique Eleb, 'HBM à Paris: Le 124-126 Avenue Daumesnil, d'Auguste Labussière, Fondation Groupe Des Maisons Ouvrières' (Laboratoire Architecture, culture etsociétés XIXe - XXe siècles; Ministère de l'équipement, du logement, des transports et de la mer /Bureau de la recherche architecturale (BRA), 1991); Youri Carbonnier, *Les Premiers Logements Sociaux En France* (La Documentation Francaise, 2008); Ford, 'The Paris Housing Crisis and a Social Revolution in Domestic Architecture on the Eve of the First World War'.

[178] Loyer, *Le Siècle de L'Industrie*, 271. « … structure de béton armé, construction de brique; urbanisme d'îlots, a grandes cours ouvertes, plantées; perspectives obliques, enrichissements des combles ... Le modèle architectural des 'logements hygiéniques' était défini ; manquait un modèle urbain réellement efficace: le principe l'urbanisme d'îlot y répondra - exprimant l'abandon du parcellaire traditionnel au profit d'une composition globale des quartiers. »

[179] Dumont, 'La Fondation Rothschild et Les Premières Habitations à Bon Marché de Paris, 1900-1925'; Dumont, *Le Logement Social à Paris : 1850-1930. Les Habitations à Bon Marché*.

> staircase they are usually dressed as for the street … Thanks, therefore, to the size of these windows, we find that the amount of light and air attainable in the rooms (and none of the rooms are dark) is considerably increased both by day and night … The plan of a really wholesome room is constructed by the aid of two reforms, one being concerned with the planes of lighting and the other with the arrangement of surfaces.[180]

Rey had himself adopted his approach to courtyards from Eugène Hénard's (1849-1923) original designs for the *redan*-type blocks of Parisian *immeubles* described in Chapter 4 under the 1902 revised street regulations. Dumont also singles out a number of key events prior to the Rothschild competition: the 1885 publication of George Picot's pivotal work *Un devoir social et les logements d'ouvriers*; and the *1er Congrès International des H.B.M* held in Paris in 1889, followed swiftly by the formation of the *Société Française des Habitations à bon marché* by Third Republic advocates of HBMs such as Picot, Émile Cheysson and Jules Siegfried.[181] The last gentleman successfully passed a law in 1894, subsequently named after him as a prominent French politician, encouraging the establishment of privately-funded foundations for the construction of HBMs – which laid the ground for the Rothschild Foundation's activities in this field.

There has been less focus on the specific use of reinforced concrete and cement systems in HBMs, though some of this has been picked up along the way by those who have researched related aspects of architectural and construction history. The historic buildings in the case study at the end of this chapter feature a Parisian HBM by Sauvage with his close collaborator Charles Sarazin, whose brother Paul was also involved as an engineer and administrator; this was completed for the *Société des Logements Hygiéniques à Bon Marché* (SLHBM) at 7 rue de Trétaigne in 1904.[182] The then French Minister, Georges Trouillot, congratulated the Society for its combined efforts to combat physical, moral and social ill-health, indicating that the Government would be doing the same, while conveniently noting that the immensely wealthy Paris-based Rothschild family

[180] H. Frantz, 'The Rothschild Artizans Dwellings in Paris Designed by Augustin Rey', *The International Studio* 110 (April 1906): 115–28.
[181] Dumont, *Le Logement Social à Paris : 1850-1930. Les Habitations à Bon Marché*, 19–20.
[182] Sauvage and Sarazin were two of the co-proprietors of the SLHBM. The others included Sauvage's mentor, the respected Parisian *Art Nouveau* architect Frantz Jourdain, as well as Amédée Dherbécourt, a socialist councillor in the 18ème arrondissement. Jean-Baptiste Minnaert, *Henri Sauvage Ou l'exercise Du Renouvellement* (Norma, 2002), 91.

had just donated 10 million francs towards the construction of more such buildings in the capital.[183] Minnaert included the HBM at 7 rue de Trétaigne in his extensive compendium of Henri Sauvage's works, noting how the architect was attempting to respond to the new building design norms of his age, but became conflicted between Eclecticism (illustrated in his metallic HBM at the *Cité L'Argentine* in Paris, see Chapter 5) and Rationalism:

> With his conception of the HBM, Sauvage went beyond the elitism of Art Nouveau and gradually distanced himself from the tectonic ornament advocated by Viollet-le-Duc and the ideal of the total work of art … The diktat of profitability led to austerity which, however, was no more acceptable to the architects than to commissioners and users.[184]

Minnaert later highlighted the problems associated with the building's uneconomic construction, when it was principally designed to offer affordable rents to the inhabitants. To him, the facade defined a decoupling of the expression of the HBM's skeleton from the role of external decoration, such that "if picturesqueness and seductiveness are essential facets of the attractiveness of workers' housing, they contradict the key requirement of economy."[185] Carbonnier singled out the same HBM as an early example of the use of reinforced concrete in French social housing with an industrial architectural theme to it (see Chapter 6 for more on this), as well as emphasising the novelty of the building framing.[186]

The other two HBMs in the case study at the end of this chapter are 32 rue Marconi in Brussels metropole by Belgian architect Léon Govaerts (1860-1930) completed in 1902 and the complex at rue de la Saïda in Paris by French architect Auguste Labussière (1863-1956) completed in 1914, each built for different social housing organisations. The first building was referenced in Chapter 2 under the key structural requirements of structural efficiency and street decor, given its unique approach to both of these. Carbonnier used the later

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[183] 'M. Trouillot à Montmartre', *L'Humanité*, July 1904, 2.
[184] Minnaert, *Henri Sauvage Ou l'exercise Du Renouvellement*, 114–15. « Avec la conception de HBM, Sauvage dépasse l'élitisme de l'Art Nouveau et prend progressivement ses distances avec l'ornement tectonique prôné par Viollet-le-Duc et avec l'idéal de l'œuvre d'art totale … Le diktat de la rentabilité entraîne une austérité qui pour autant, n'est pas plus acceptable par les architectes que par les décideurs et par les usagers. »
[185] Jean-Baptiste Minnaert, *Henri Sauvage* (Éditions du Patrimoine, 2011), 81. « Si le pittoresque et la coquetterie sont des données du programme essentielles pour l'attractivité des logements ouvriers, ils contredisent l'exigence d'économie. »
[186] Carbonnier, *Les Premiers Logements Sociaux En France*. Sauvage and Sarazin moved on to a patented system of *maisons à gradins* first tested in an *immeuble* for private tenants on rue Vavin that was completed in 1913 (see Chapter 6)

HBM complex at rue de la Saïda to illustrate the improved employment of reinforced concrete in a Parisian HBM, in what he thought was a more targeted manner than at 7 rue de Trétaigne, where one might argue that the economics had worked against the novel materials-system:

> The concrete stairs are also in the open air and so ventilated, as if it were necessary to clearly show how the new materials could answer all the questions posed by the HBM movement: sanitation, economy and social education - such stairs not only prevented tuberculosis, they also prevented unproductive gatherings.[187]

It could now be hailed as an exemplary use of more visible reinforced concrete, through Hennebique's fully mature *béton armé* system, allowing practical solutions to affordability and disease prevention for the worse off in urban society; however Carbonnier subsequently puts a damper on his own fervour by inferring that, despite the advances made by French social housing movements in Paris and elsewhere in France before the First World War, there were still severe problems to be found in the industrial conurbation that comprised Lille and its neighbouring textile cities. He noted that in 1911, despite the efforts of several construction companies, there were still 882 courtyards and street dead-ends that contained 16% of the Lille population, while in neighbouring Roubaix, 47% of the population used 1524 small courtyards. Such poorly ventilated, ill-lit urban spaces always suffered the most during epidemics.[188]

Ford makes the connection between a *Belle Époque* hygienic approach to architecture in Paris and the rise of International Modernism after the First World War. While previously innovation in domestic architecture had first appeared in the luxury housing market and then this was transferred into working-class habitation, just before and after the war this trend was reversed. Ford noted that the Modernist architect Rob Mallet Stevens had already observed in 1911 that all of society enjoyed a new level of domestic comfort; he saw the "role of modern architecture" to be one of "organizing a practical, hygienic, and convenient design in which air and light reign supreme".[189] Clearly there were other factors at work in the urban environment in addition to a

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[187] Carbonnier, 132. « Les escaliers en béton sont par ailleurs largement ouverts et ventilés, comme s'il fallait montrer de façon nette à quel point les nouveaux matériaux pouvaient répondre à toutes les questions posées par le mouvement des HBM: salubrité, économie et éducation sociale - de tels escaliers n'évitent pas que la tuberculose, ils permettent aussi d'éviter les rassemblements stériles »
[188] Carbonnier, 245.
[189] Ford, 'The Paris Housing Crisis and a Social Revolution in Domestic Architecture on the Eve of the First World War', 617.

concern for hygiene, but the importance of fresh air and access to sunlight is worth noting, the difference being that Mallet-Stevens and his 1920s French architectural contemporaries were designing at that time for the wealthy rather than the less advantaged.

Case study: Three HBMs in Brussels and Paris

The still extant four-storey HBM at 32 rue Marconi (formerly rue Verte) in Brussels, originally completed in 1902, is the earliest such type of social housing in either France or Belgium to use a reinforced concrete system in its construction. It was protected in 1997 by the Brussels Region due to its architectural significance, mainly linked to the unique street facade designed to an Egyptian theme and made of cement facade cladding on a concrete frame, all with a timber cornice at the top (Figures 2.1 (a) and (b)).

Figures 2.1 (a) and (b): The street facade of the HBM at 32 rue Marconi, Brussels (Govaerts, 1902), in the early 20th century (left) and today (right). Both illustrate the Egyptian decorative facade cladding used by architect Léon Govaerts. (FRT 2.51 CRM et Sites, Rue Marconi 32. Urban Brussels & Nick von Behr)

The *Société Anonyme d'Habitations à Bon Marché de l'Agglomération Bruxelloise* (SAHMB)[190] commissioned Léon Govaerts to design and build an HBM in the commune of Forest, then on the edge of the city of Brussels, now fully incorporated in the metropolis. The HBM at 32 rue Marconi was completed in 1902 and sensitively

[190] Now known as *La Société Bruxelloise des Habitations*.

renovated by 2013 – it is still used (at least partially) for its original purpose of social housing, another unique feature when compared to the historic example buildings. The earliest reference to the HBM is in a 1902 edition of *Le Béton Armé* under a listing of works carried out that year in Belgium using the *béton armé* system which probably misspells the name of the commissioning organisation.[191] However we do not know if the notice is about the HBM at 32 rue Marconi (then called rue Verte) or another HBM on the street also completed using reinforced concrete systems. There is a short but perceptive reference to Govaerts and 32 rue Marconi in a 1970s book about *Art Nouveau* architecture in Brussels, which covered many much better known buildings in that expressive architectural genre for which the Belgian metropolis became famous. The authors saw Govaerts using the language of *Art Nouveau* as a stylistic morphology that did not affect the general technique of composition, the relations between floors or building symmetry:

> It is a question of scale. Govaerts' is a modern style only in the details, such as the ironwork, the connections between the balconies, the cornices where he inserts air intakes and, finally, the modeled lintels of the windows, with thin dentils.[192]

Basyn examined the history of SAHBM with its goal of providing a better life for Brussels workers and their families.[193] Govaerts had not previously built any social housing – one can only assume he was chosen because he had already used the Hennebique *béton armé* system elsewhere in Brussels and the building commissioners wished to test that novel materials-system approach in social housing; just as this would be done in Paris a few years later with the HBM at 7 rue de Trétaigne by Sauvage and Sarazin (the subsequent example building in this case study). There are no known direct links between these two buildings, or the architects or the commissioning and constructing organisations. However Basyn noted that Govaerts, like his better-known contemporary Victor Horta, was a pupil of the respected Belgian architect Ernest Hendrickx, who himself had been a pupil of Viollet-le-Duc in Paris.[194] Govaerts had studied for three years in Paris in the early 1880s and

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[191] « 14654. —N° Cité ouvrière à Bruxelles (Belgique). Propriétaire : la Société anonyme des logements à bon marché. Architecte: M. Govaerts. »'Relevé Des Travaux Executés 1902', *Le Béton Armé*, 1902, 22.

[192] Franco Borsi, Robert Delevoy, and Hans Wieser-Benedetti, *Bruxelles Capitale de l'Art Nouveau* (In Arch, Officina, 1972), 87. « C'est une question d'échelle. Govaerts n'est modern style que dans les détails, comme la ferronnerie, les raccords entre les balcons, les corniches ou il insère les prises d'air et, enfin, les linteaux modelés des fenêtres, avec de minces denticules. »

[193] Jean-Marc Basyn, 'Léon Govaerts (1860-1930). Un Architecte de Transition.' (University Catholique de Louvain, 1992), 89–90.

[194] Basyn, 13. Ernest Hendrickx had first applied Viollet-le-Duc's principles with his 'Model School' in Brussels of 1879 and the 1884-5 Brussels University building. Françoise Dierkens-Aubry and Jos Vandenbreeden, *Art Nouveau in Belgium. Architecture and Interior Design.* (Duculot, 1991), 65.

may have there made contact with aspiring young French architects caught up in the post-Haussmannian architectural debates about Eclecticism and rationalism in the city capital. Finally, he was Vice-President from 1892-4 and 1899-1900, and then President from 1900-02, of the Belgian Society of Architects (SCAB), which no doubt put him in contact with other key architects in both Belgium and France, as well as adding to his overall credentials. We also know from other sources that Govaerts had later designed and built work offices for a leading Hennebique contractor in Brussels.[195] Hellebois simply confirmed later that Govaerts had designed seven buildings in Brussels that employed a reinforced concrete system, from houses to town halls.[196]

It appears that designs by Govaerts and two other local architects were used by the SAHBM on the same, specially-widened street in the commune of Forest, in order to test out three models for a new style of multi-storeyed social housing accommodation block for Brussels workers and their families.[197] Basyn describes Govaerts' building at 32 rue Marconi in more detail based both on his personal observation and available written and drawn evidence from archives of the 1990s, before the HBM was renovated. He noted how the building rose from a bluestone basement on three floors with two apartments each, giving a total of eight workers' apartments in the HBM; the grainy texture of the moulded cement facade was punctuated by smoother decorative features:

> The building is crowned with an important and original wooden cornice. The facade, quite sad in the colour of its coating and its geometric monotony, offers an unexpected *Art Nouveau* stamp that appears to us especially through the very original treatment of the entrance porch.[198]

The reference to the 'sad' facade was a recognition of how much this key external component of the building had deteriorated since its original construction. The HBM at 32 rue Marconi contrasted with distinctive private *hôtels* in the Belgian capital first designed by the 'founder' of the *Art Nouveau* architectural genre of Eclecticism, Victor Horta, from 1893 on. Few if any of these were known to have used the novel materials-

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[195] Matthijs Degraeve et al., 'Spatial Management of Contractors. An Analysis of the Industrial Sites of the Louis De Waele Enterprise in Brussels (1867-1988)', in *Building Knowledge, Constructing Histories. Volume 1 : Proceedings of the Sixth International Congress on Construction History*, ed. Ina Wouters et al. (CRC Press, 2018), 531.
[196] Hellebois, 'Theoretical and Experimental Studies on Early Reinforced Concrete Structures', 83.
[197] Basyn, 'Léon Govaerts (1860-1930). Un Architecte de Transition.', 90.
[198] Basyn, 90–91. « L'immeuble est couronné d'une importante et originale corniche en bois. La façade, assez triste par la couleur de son enduit et sa monotonie géométrique, offre un cachet Art Nouveau inattendu qui nous vient surtout par le traitement tellement original du porche d'entrée. »

system. In a workmanlike analysis of Govaerts' whole set of identified works, Basyn suggests that the HBM at 32 rue Marconi fits with a mature stage of *Art Nouveau*, reminiscent of the geometric Viennese Succession approach employed by Otto Wagner, Josef Hoffmann and their peers; Basyn validates this by noting that Hoffmann designed and built the archetype for this new derivation, the *Palais Stoclet* in Brussels in 1911, though there is no mention of the use of reinforced concrete or cement systems in that later building.[199] However, some aspects of Basyn's argument are developed under an examination of *Belle Époque* Eclecticism in Chapter 5.

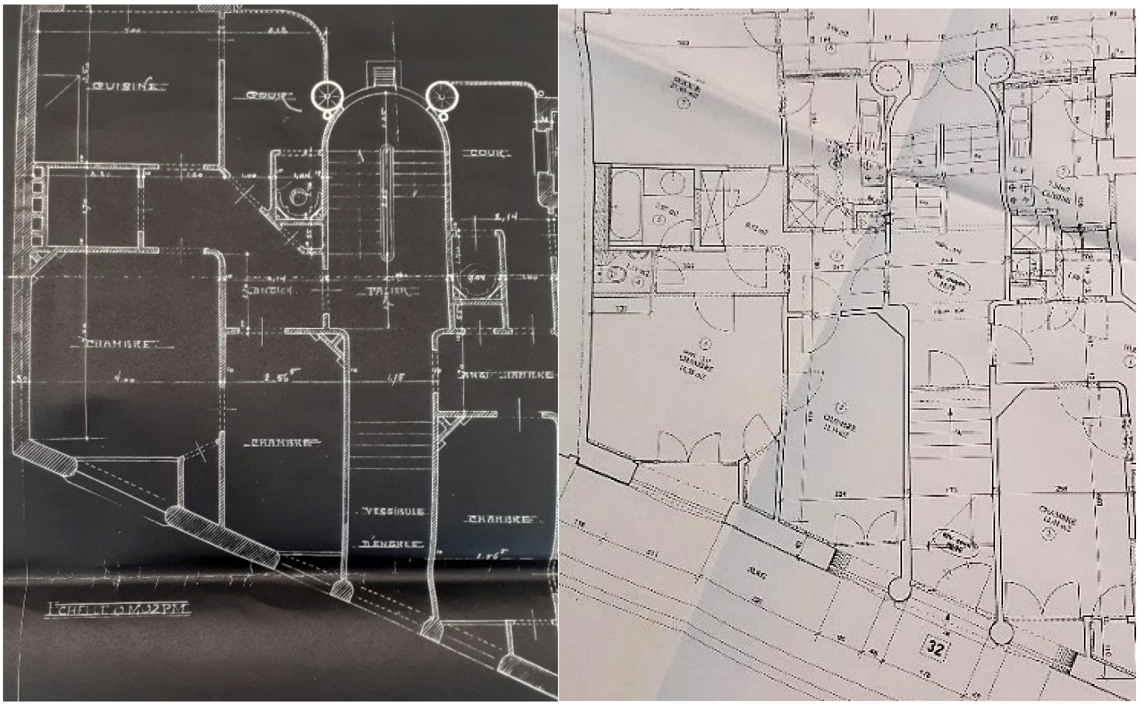
In terms of deciding whether or not François Hennebique's *béton armé* system was actually used at the HBM at 32 rue Marconi, there are no definitive original records confirming one way or the other in the CAAC's Hennebique files or in Brussels heritage archives. While Govaerts' earlier project at former *Banque Brunner* definitely used the novel materials-system, it had completely different functional requirements. Van de Voorde first attempted to review the matter in her extensive doctoral thesis on the history of Belgian reinforced concrete.[200] She pointed to a 2007 study by an architectural engineer which had shown an unusual use of reinforced concrete in the structure. According to van de Voorde, the floor slabs had been reinforced with single rods heading in one direction only, rather than the more usual trellis pattern for rebars; she noted also that the load on these floors was transmitted directly to the inner walls through supporting reinforced concrete columns with brick infill.[201] There is at Urban Brussels (FRT 2.51 *Commission Royale de Monuments et Sites* Rue Marconi 32 Boite no 1 1996-2007) an email from the same architectural engineer dated September 2006, in which she provides brief notes of a visit to the building a month before; she maintained that all of the building framing was completed using reinforced concrete, however, she did not specify whether the *béton armé* system was used or indeed whether it was employed in a monolithic way with the floors for the whole of the building. The same Urban Brussels archive also has a copy of a later November 2006 pre-renovation report by the project architects, which noted that the internal walls were part of what appeared to be indeed a reinforced concrete building framing and that the staircase shell was also made from reinforced concrete, but again with no identification of the precise materials-system used. A later report of early 2007 by the same architectural team included colour photographs of the (reinforced) concrete columns and beams of this

[199] Basyn, 115.
[200] Voorde, 'Bouwen in Beton in België (1890-1975) Samenspel van Kennis, Experiment En Innovatie', 107–8.
[201] Voorde, 108.

building framing (with its interior brick infill) after the removal of covering materials to permit a fuller inspection (Figure 2.2).

Figure 2.2: 2007 photographs of exposed (reinforced) concrete from a report on the structure of the HBM at 32 rue Marconi, Brussels (Govaerts, 1902), with no indication of the exact system used by the architect Govaerts. (FRT 2.51 CRM et Sites, Rue Marconi 32. Urban Brussels)

Finally, there is a separate section of that 2007 report which indicates an extensive programme of renovation of at least the metallic parts of the reinforced concrete building framing and floors; this was planned to be undertaken, but again there is no exact indication of the original system used or further records showing what was actually discovered during this part of the renovation. There are a number of architectural drawings for the HBM at 32 rue Marconi held at Urban Brussels, both originals by Govaerts and later ones by the architects for the building renovation this century, who used the originals as guidance. However the precise nature of the system used for the building framing and floors is not clear from these diagrams, even after juxtaposing similar aspects of the plans and sections of the building (Figures 2.3 (a) and (b)).



Figures 2.3 (a) and (b): Comparison of original design plan, 1902 (left) and later renovation plan, 2006 (right) for the ground floor of the HBM at 32 rue Marconi, Brussels (Govaerts, 1902), with little indication of reinforced concrete system used. (File 2322/Mon32. Ministère de la region de Bruxelles-Capitale. Urban Brussels)

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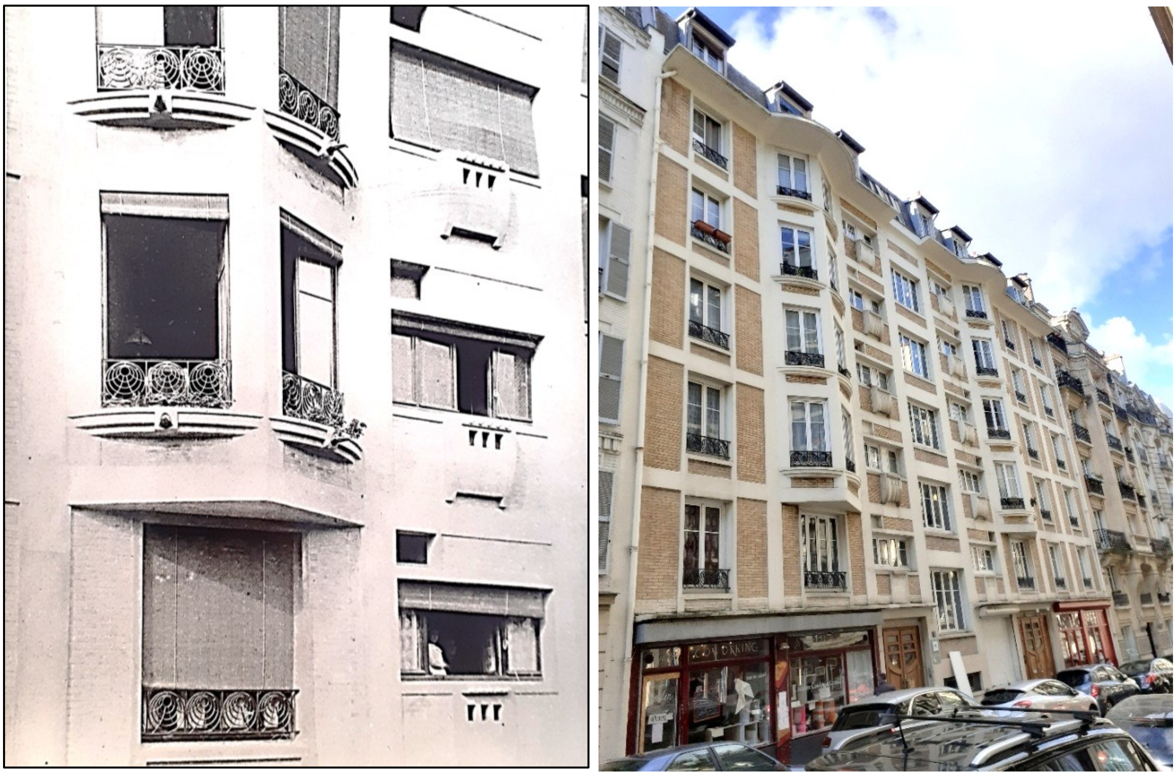
The second building in this case study is an HBM at 7 rue de Trétaigne, which was the first to use reinforced concrete building framing (but not floors) in Paris. The SLHBM commissioned Henri Sauvage and Charles Sarazin to design and build its first HBM at an available site in the 18ème arrondissement of Paris, and it was completed in 1904. The modern facade no longer has lime-wash and the now apparent yellowish colour of the clay bricks contrasts the plain building framing (Figures 2.4 (a) and (b)). An article appeared in the 4 July 1904 edition of *L'Humanité* describing the inauguration the previous day of the HBM at 7 rue de Trétaigne by the French Minister of Commerce and Industry in the radical government of Prime Minister Émile Combes.[202] The piece quoted from the inaugural speech by the 'father' of Parisian *Art Nouveau*, Frantz Jourdain (see Chapter 5), who was also the chief administrator of the SLHBM and was clearly proud of the political motives behind

[202] 'M. Trouillot à Montmartre'.

the construction project that had driven the building's commissioning needs, converted into structural requirements:

> So we did not undertake a work of philanthropy, but a work of human solidarity ... Thus, in this building we find not only lodging and food at the best prices, but also elements of intellectual culture and moral life. And, it is a really beautiful idea to have built this model house, a work inspired by a free spirit of solidarity, next to the *Sacré-Coeur*, to have thus put a torch near the extinguisher.[203]



Figures 2.4 (a) and (b): The HBM at 7 rue de Trétaigne, Paris (Sauvage & Sarazin, 1904), with original lime-washed street facade, n.d. (left), and the street facade today with no lime-wash and original yellow clay bricks exposed (right). (18 Ifa B6/20. CNAM/SIAF/Cité de l'architecture et du patrimoine/Archives d'architecture contemporaine & Nick von Behr)

The author of the article described the HBM with its thirty apartments offering plenty of fresh air, natural light and hygiene to the occupants, for which they paid between 340 to 380 francs annual rent. *La Construction Moderne* reported on the HBM at 7 rue de Trétaigne a week later in a much briefer piece and with slightly different information about the number of apartments contained within it, only twenty according to the

[203] 'M. Trouillot à Montmartre', 2. « Nous n'avons donc pas fait une oeuvre de philanthropie, mais une oeuvre de solidarité humaine … Ainsi, on trouve dans cet immeuble, non seulement le gîte et la nourriture au meilleur compte, mais encore les éléments de culture intellectuelle et de vie morale. Et, c'est une idée vraiment belle d'avoir construit cette maison modèle, oeuvre inspirée par un libre esprit de solidarité, à côté du Sacré-Coeur, d'avoir mis ainsi près de l'éteignoir le flambeau. » The nearby church of the *Sacré-Cœur* at Montmartre had been completed recently as a tribute to the deceased of both the disastrous 1870 Franco-Prussian War and the subsequent Paris Commune, hence Jourdain's allusion to extinguishing life.

author. The article also noted how in his inaugural speech Frantz Jourdain had thanked Mme Weill for her donation to the building, as well as explaining how Henri Sauvage had succeeded in putting hygiene measures into practice, by avoiding materials and architectural or interior features that would be inimical to the required high standards of cleanliness.[204]

Dumont included 7 rue de Trétaigne in her historical research into the construction of Parisian HBMs, referencing the original designs held at the Archives de Paris (see Figure 2.5).[205] The building included 29 'logements' (of more than one room) and 9 'chambres' (with presumably single rooms). She highlighted the surprising sincerity of the reinforced concrete building framing with clay brick infill for the facade walls (instead of original proposed glass bricks), pointing to the use of *porphyrolite* as a chemical paste to protect the wooden floors and aid with cleaning, sealing the joints between floors and interior partition walls.[206]

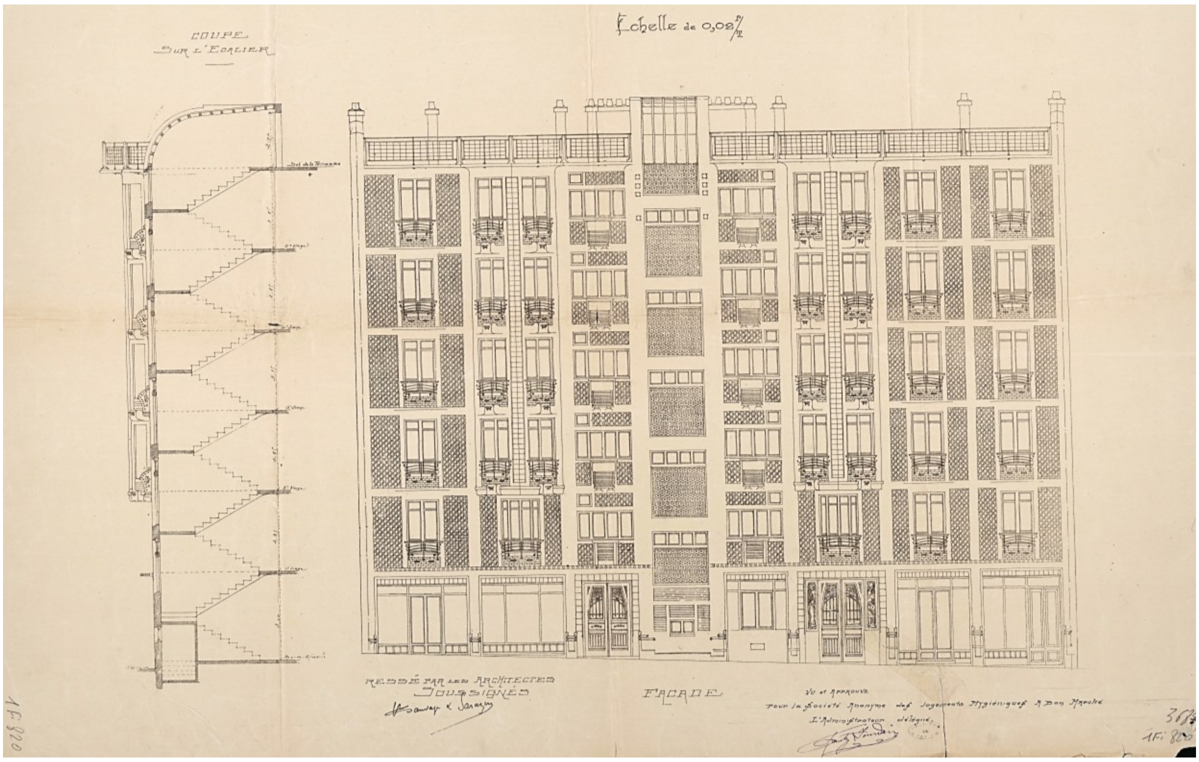


Figure 2.5: Original architectural designs for a section and the street facade, HBM at 7 rue de Trétaigne, Paris (Sauvage & Sarazin, 1904) showing bay and other types of windows, no date. (AD075FI_1FI_0820. Archives de Paris)

[204] 'Société Des Logements Hygiéniques à Bon Marché', *La Construction Moderne* 9, no. 41 (1904): 492.
[205] Dumont, 'La Fondation Rothschild et Les Premières Habitations à Bon Marché de Paris, 1900-1925', 28-9,242.
[206] According to Minnaert the substance was made of cement, sawdust and magnesium powder and was washable and insulated against excessive noise and cold. Minnaert, *Henri Sauvage Ou l'exercise Du Renouvellement*, 358.

The rooms had different types of window depending on functional requirements: vertical for the bedrooms, bay windows for the communal rooms, horizontal for the kitchens, staggered for the staircase landings. A year after Dumont's report, Bullock and Read included the HBM at 7 rue de Trétaigne as an example of a novel approach to social housing that used reinforced concrete or cement building framing, evidently visible in the street facade:

> … the infill was brick, although it was originally to have included ceramic tile, a material favoured in the early 1900s for its hygienic qualities. The building was completed by a roof garden, although this was later replaced by a mansard roof … The Rue Trétaigne was the most striking [of 6 blocks by SLHBM 1903-09] in its revelation of its structure … Sauvage took advantage of the relaxation of the building regulations in 1902, which gave greater freedom to use bow windows.[207]

The Paris street regulations on bay windows (which included bow windows and oriels) had in fact been relaxed as early as the 1880s, though admittedly greater architectural freedoms arose after the 1902 revisions to the same regulations (see Chapter 4). More importantly, according to this analysis, the street facade brick infill was originally planned to include ceramic tile cladding, presumably discarded on the same economic grounds as the glass bricks, and the leaky flat roof-terrace was eventually replaced by a mansard roof.[208]

François Loyer referenced the HBM at 7 rue de Trétaigne in his book about Parisian nineteenth-century architecture, specifically noting the use of reinforced concrete and its wider structural and aesthetic implications.[209] Dumont subsequently expanded on her original research report in a book, providing comprehensive details on the additional communal space in the HBM at 7 rue Trétaigne, including on the ground floor a small bath-shower room and the premises of the workers cooperative *La Prolétarienne* with its grocery store, refreshment bar, restaurant, and popular university, with conference room and library.[210] She also made a much stronger assertion about the significance of the building framing with brick infill from an industrial architectural perspective:

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[207] Bullock and Read, *The Movement for Housing Reform in Germany and France 1840-1914*, 399.
[208] Bullock and Read, 399.
[209] François Loyer, *Paris XIXe Siècle. L'Immeuble et La Rue* (Fernand Hazan, 1987), 414.
[210] Dumont, *Le Logement Social à Paris : 1850-1930. Les Habitations à Bon Marché*, 24–25.

> For construction, Sauvage had adopted a technique still poorly known and limited to industrial premises: the reinforced concrete building framing, left visible with its brick fillings. This is the first apartment building designed in this way in France.[211]

In terms of visible reinforced concrete building framing in the street facade, the building's design was just preceded by the *immeuble* at 25b rue Benjamin Franklin by the Perret brothers completed earlier in the same year (see Chapter 6). Dumont noted that the newly finished building was visited in 1904 by members of the *Congrès International d'Assainissement et de Salubrité de l'Habitation*.[212]

Jean-Baptiste Minnaert still remains the acknowledged expert on Henri Sauvage, 30 years after his original doctoral thesis on the French architect. He noted that the HBM at 7 rue de Trétaigne won first prize (*ex-aequo*) at the 1908 *Concours d'Habitations à Bon Marché* and that the planned glass bricks first mentioned by Dumont were made by the French manufacturer Falconnier. [213] Réjean Legault's subsequent PhD research summarised the wider architectural significance of the HBM at 7 rue de Trétaigne:

> Both the rue Trétaigne building by Sauvage and the rue Franklin by Perret were viewed as decisive progress beyond the mistaken essay of the architect Auscher in the rue de Rennes, where the new material was used for its plastic quality.[214]

Here is where we return to Minnaert, who fully expounded his own and Legault's doctoral analysis in a comprehensive book on Sauvage.[215] Minnaert's account tells us how the many radical features of the rue de Trétaigne building inspired Augustin Rey in the project that won him first prize in the Rothschild Foundation's 1905 HBM design competition, while the reinforced concrete roof-terracing was designed to combat

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[211] Dumont, 25. « Pour la construction, Sauvage avait adopte une technique encore mal connu et limitée aux locaux industriels: l'ossature de béton armé, laissée apparente avec ses remplissages en brique. Il s'agit du premier immeuble d'habitation ainsi conçu en France. »
[212] Dumont, 25.
[213] J.-B. Minnaert, 'Henri Sauvage. Architecte (1873-1932)' (Université Paris IV – Sorbonne, 1993), 75 (Catalogue).
[214] Legault, 'L'Appareil de L'Architecture Moderne: New Materials and Architectural Modernity in France, 1889-1934', 94. Legault references here the *immeuble* at 25b rue Benjamin Franklin (see Chapter 6) and the *Maison Felix Potin*, a department store completed in 1904 and designed by the French architect Paul Auscher with a famous facade permitted by the new Paris street regulations of 1902. In effect it was a more extravagant and much larger version of the *immeuble* at 1 rue Danton (see the case study of the building in Chapter 4), which had like it used the *béton armé* system. 'Maison Potin, Rue de Rennes, Paris', *La Construction Moderne* 10, no. 13 (December 1904): 149.
[215] Minnaert, *Henri Sauvage Ou l'exercise Du Renouvellement*.

tuberculosis by allowing inhabitants access to unblocked daylight and perhaps fresher air. Minnaert also noted that many of the apartments had three rooms and that this broke with standard practice at the time of crowding families into two rooms. Like Legault, he affirmed the link between the reinforced concrete building framing and rationalist advocates of the visibility of a building's tectonics such as Anatole de Baudot. Minnaert saw reinforced concrete as a pragmatic choice by the architect partners, connected to a need for secure foundations in the poor ground that was found in the locality; but ultimately if was not used again by them in an HBM until a building they designed and constructed at 163 Boulevard de l'Hôpital, also in Paris (completed in 1909). But more importantly, the decision to use Falconnier glass bricks in the wall infills and so allow maximum daylight into the apartments, was inextricably connected to the employment of a reinforced concrete building framing. As Dumont had earlier indicated, the SLHBM had indeed decided against this expensive measure, concerned at the cost of replacing many of these glass bricks over time. Minnaert compared the HBM at 7 rue de Trétaigne with both the Perret brother's private *immeuble* at 25b rue Benjamin Franklin (see Chapter 6) and the later HBM complex at rue de la Saïda by Labussière:

> … [Henri Sauvage and Auguste Perret] powerfully affirmed the monumental role of their reinforced concrete structures, understanding that this component, so as to represent not just the building's construction but more fundamentally its architecture, had to respond to principles of eurythmy and modularity … [the HBM's] fame stretched to other solutions that were applied, for which it had a certain precedence.[216]

As already noted, Carbonnier mentioned the HBM at 7 rue de Trétaigne in his comprehensive study of early social housing in France that was largely centred on Paris, picking up on the novel effect of the reinforced concrete building framing with brick infills. He maintained that while the building conformed with received *Belle Époque* wisdom that decoration should be banned from workers' housing, it also affirmed, through its own unique architectural language, the originality of bringing an industrial context into wider urban society. On the other hand, according to Carbonnier the SLHBM "seems to have been frightened, since they did not allow the experience to be repeated." [217] The experiment was in fact repeated a few years later by the SLHBM

[216] Minnaert, 96,99. « … les deux architectes affirment aussi puissamment l'un que l'autre le rôle monumental de la structure en béton armé, et comprennent que cette structure, pour n'être pas seulement de la construction mais plus fondamentalement de l'architecture, doit répondre à des principes d'eurythmie et de modularité … Sa renommée assure à quelques uns des solutions qui y sont appliqués un certain postérité. »
[217] Carbonnier, *Les Premiers Logements Sociaux En France*, 193.

with an HBM at 163 Boulevard de l'Hôpital in Paris completed in 1909 with a reinforced concrete skeleton and designed by the same architect partnership, even though it also proved less economically viable as affordable housing than HBMs completed with traditional building materials.[218]

Fanelli and Gargiani used the HBM at 7 rue de Trétaigne as an illustration of Henri Sauvage's engagement with the then novel concept of making metallic-based (though lithic clad) building framing visible in the facade of everyday urban structures.[219] Ford also referenced the building in her paper on Parisian social housing during the *Belle Époque*, employing it to exemplify a counter-argument by the SLHBM and its proponents to that of Julien Guadet, who had announced that it was impossible to build both comfortably and hygienically for the working classes; she compared this to the early French Impressionist painters who had displayed their art in a *salon des refusés*. In such a way "private foundations and building societies established to construct low-cost housing provided architects the opportunity to do so."[220] While Gillet did not select the HBM as one of his five detailed case studies of reinforced concrete skeleton buildings in his doctoral thesis, he did single it out as a contrast to the use of ceramic tiling or porcelain stoneware to clad non-monumental, urban buildings, as well as the monumental *Théâtre des Champs-Elysées* by the Perret brothers, completed in 1913:

> One of the main effects of the rational use of ceramics was to lead to a fragmentation of integrated cladding: large portions of residual plaster, or even entire sections of brick infill, were used between ceramic sections, a solution already experimented with by Henri Sauvage in 1903 when constructing the facade of his building on the rue de Trétaigne.[221]

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[218] This still extant HBM is interesting in that Sauvage and Sarazin employed ceramic cladding on the facade and designed loggias on the roof, sadly all since removed. Minnaert, *Henri Sauvage Ou l'exercise Du Renouvellement*, 105–7.
[219] Giovanni Fanelli and Roberto Gargiani, *Histoire de l'architecture Moderne. Structure et Revêtement.* (Presses polytechniques et universitaires romandes, 2014), 185.
[220] Ford, 'The Paris Housing Crisis and a Social Revolution in Domestic Architecture on the Eve of the First World War', 607.
[221] Gillet, 'Conception et Confection. Une Histoire Matérielle Du Revêtement Céramique Des Immeubles Parisiens (1900-1914)', 193. « Un des principaux effets de l'usage rationné de la céramique fut d'entraîner un morcellement du revêtement intégral: entre les pièces de céramique, on assista à l'affleurement de larges portions d'enduit résiduelles, voire de pans entiers de murs de briques de remplissage, solution déjà expérimentée par Henri Sauvage en 1903 pour la construction des façades de son immeuble de la rue de Trétaigne. »

The final building in this case study of HBMs is the complex at rue de la Saïda in Paris, an extant social housing site in the 15ème arrondissement originally commissioned in 1912 from its architect Auguste Labussière by the *Groupe des maisons ouvrières* (GMO), which in 1917 became the *Fondation Lebaudy* that still owns it to this day. The first two sets of blocks, containing units of 60 apartments for poorer families and then an annex of 14 apartments for elderly men, were both completed by 1914 (Figures 2.6 (a) and (b)).

Figures 2.6 (a) and (b): The HBM complex at rue de la Saïda, Paris (Labussière, 1914) after completion of the first units in 1914 (above) and as they are today (below), showing the building framing and brick infill with polychromy at the top and bottom, as well as open staircases. (76 Ifa 9/8. CNAM/SIAF/Cité de l'architecture et du patrimoine/Archives d'architecture contemporaine & Nick von Behr)

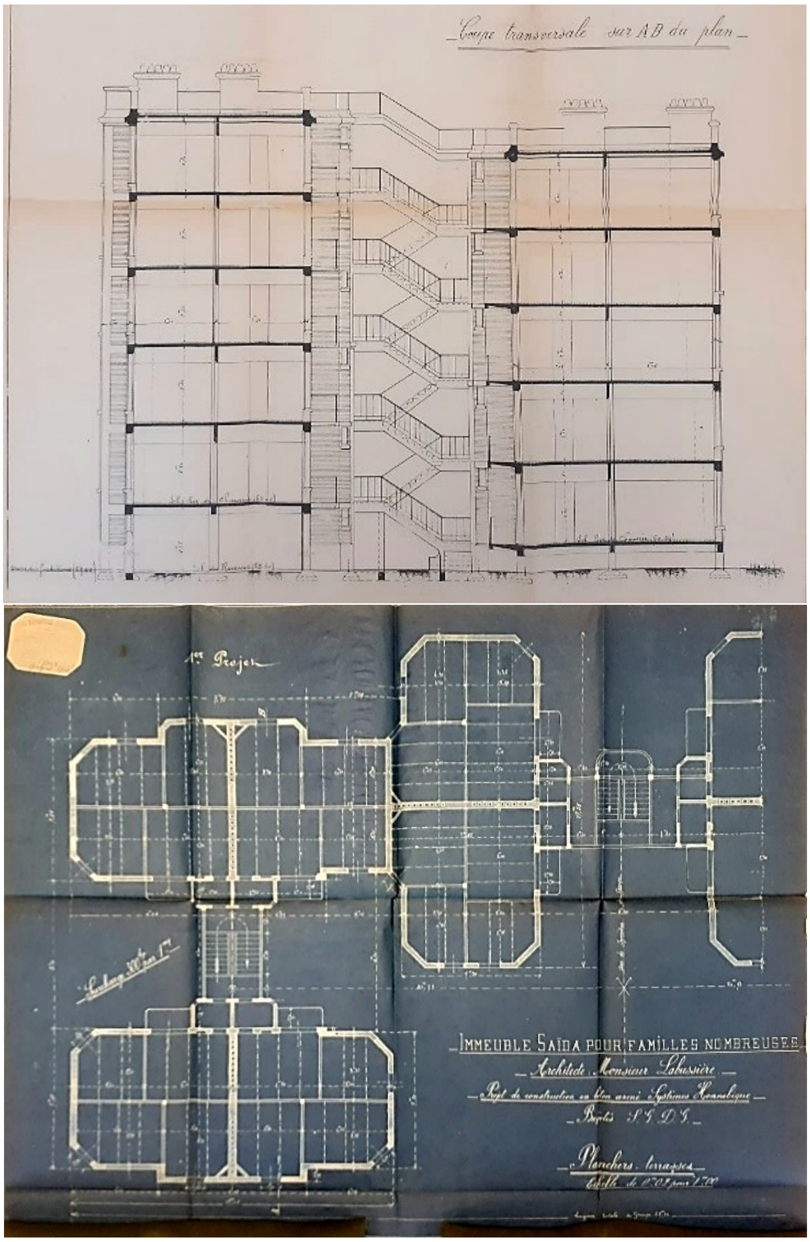
The contractor was M. Chaussivert, a Hennebique *concessionnaire*, and the many archival papers held in the Hennebique archives in Paris confirm the use of the *béton armé* system for the building framing of the separate blocks (CAAC: BAH 076 IFA 9/8, 1354/20, 1556/4). These same archival records contain a letter of 1908 from François Hennebique to Chaussivert's office asking them to produce technical designs to a proposed site plan by the architect Augustin Rey for a similar project on rue de la Saïda. They also include subsequent architect's drawings by Labussière from 1912 onwards for what would turn out to be the actual built complex, as well as accompanying technical designs from the Hennebique offices (Figures 2.7 (a) and (b)). Dumont provided an initial analysis of the buildings in her research report on Parisian HBMs for the *Ministère de l'urbanisme et du logement*, lauding the architect's accomplishments.[222] She noted that the complex had consisted of small individualized buildings, largely ventilated on all sides, and connected by fully open lateral and longitudinal staircases, which were in effect extensions of the outdoor spaces. More importantly, she made the original connection back to Sauvage and Sarazin's HBM on the rue de Trétaigne, the opposite of Minnaert's and Carbonnier's approach noted in the earlier historic example building; Dumont therefore was the first of these three researchers to highlight the significance of the visible concrete skeleton with its brick filling and roof-terrace, all with little decoration:

> By the rigour and severity in the treatment of the facades, and especially by the typology adopted - a hygienist and repetitive system, independent of the layout of the street - this HBM is certainly the most modern among the achievements of this period. It is definitely the origin of the plan, exactly identical, adopted by Tony Garnier in his whole *quartier des Etats-Unis* in Lyon in 1920.[223]

Tony Garnier's Lyon project completed after the First World War used open-air staircases for housing because it was much more conducive to the local climate than that of Paris, where it was eventually abandoned as a feature of social housing. Dumont noted the alteration of the facade design between the application for a building permit and the actual construction, with Labussière changing (Rey's original design?) from a

[222] Dumont, 'La Fondation Rothschild et Les Premières Habitations à Bon Marché de Paris, 1900-1925', 117–18.
[223] Dumont, 117–18. « Par la rigueur et la sévérité dans le traitement des façades, et surtout par la typologie adoptée - un système hygiéniste et répétitif, indépendant du tracé de la rue - cette H.B.M. est certainement la plus moderne parmi les réalisations de cette période. Elle est certainement à l'origine du plan, exactement identique, adopte par Tony Garnier dans son ensemble du quartier des Etats-Unis à Lyon, en 1920. »

picturesque brick motif to a more sober approach similar to that taken by Henri Sauvage and Charles Sarazin for their first HBM in Paris at the HBM at 7 rue de Trétaigne (see the earlier example in this case study).



Figures 2.7 (a) and (b): Design section of blocks at the HBM complex at rue de la Saïda, Paris (Labussière, 1914) (above) and corresponding structural plans by Hennebique (below), both dated 1912. The use of the béton armé system for the building skeletons and the connecting staircases is illustrated well.
(76 Ifa 1556/4. CNAM/SIAF/Cité de l'architecture et du patrimoine/Archives d'architecture contemporaine)

She also recorded that an additional 60 family housing units were added to the HBM complex after 1914. The original 60 apartments completed before the First World War each had four rooms totaling 56m^2 in area, intended for large families with more than four children. In Dumont's subsequent book, she noted how Labussière was perhaps inspired by the completion in 1909 of a much talked-about HBM on the rue de Prague in Paris for the Rothschild Foundation, which had not used reinforced concrete or cement; the layout of that building was a distinct move away from blocks with internal courtyards, following the approach proposed by Augustin Rey in 1905 for the Rothschild Foundation's HBM design competition (see earlier in this chapter).[224] A renewed use of reinforced concrete systems in social housing had also been led by Henri Sauvage and Charles Sarazin at their HBM at 165 Boulevard de l'Hôpital in 1909, learning from their first, financially unsuccessful attempt at the HBM at 7 rue de Trétaigne. Dumont tells us what Labussière did from 1909 onwards, after designing two open courtyard HBM complexes (at rue de la Bidassoa and rue de Kronstadt) and hence breaking with the normal street alignment:

> He went even further in 1912, on the occasion of his last project for the Lebaudy Foundation, rue de la Saïda. For large families, i.e. the poorest and most undisciplined (the presence of many children made maintenance difficult and costly), for a remote suburb which was still not particularly urbanised (on the edge of Paris's old walled fortifications), Labussière adopted a type of building which was the precise materialisation, seven years later, of the theories of Augustin Rey.[225]

The last sentence indicates the link between the complex and Rey's innovative HBM designs of 1905 and after. Eleb provided further details on the HBM complex at rue de la Saïda in her report for the *Ministère de l'Equipement du Logement, des Transports et de la Mer* on an extant HBM building at 124-6 avenue Daumesnil in Paris; this was completed by the same architect, Labussière, for the GMO in 1908, and also used Hennebique's system.[226] Eleb confirmed Dumont's analysis of the architect's plainer approach to the building's exterior decoration, both of them exaggerating this somewhat, as clearly this was not entirely excluded; but again emphasising how the novel materials-system was generally identified with less aesthetically desirable industrial buildings. She also included more on the hygiene role of the open staircases:

> The wide open external staircases, with exposed concrete structure, allowed access to a dwelling on each half-floor which avoided promiscuity and direct views of neighboring apartments. The layout of

[224] Dumont, *Le Logement Social à Paris : 1850-1930. Les Habitations à Bon Marché*, 97.
[225] Dumont, 97. « Il va plus loin encore en 1912, à l'occasion de son dernier projet pour la Fondation Lebaudy, rue de la Saïda. Pour des familles nombreuses, c'est-à-dire la clientèle la plus pauvre et la plus indiscipline (la présence de nombreux enfants rend l'entretien difficile et coûteux), pour un quartier périphérique encore peu urbanisé (on est en bordure du chemin de ronde de fortification), Labussière adopte un type de bâtiment qui est l'exacte matérialisation, sept an après, des théories d'Augustin Rey. »
[226] Eleb, 'HBM à Paris: Le 124-126 Avenue Daumesnil, d'Auguste Labussière, Fondation Groupe Des Maisons Ouvrières'.

> the different buildings, the open staircases corresponded with the obsession at the time for ventilation aimed in particular at preventing the spread of tuberculosis.[227]

As previously noted, Carbonnier referenced the the HBM complex at rue de la Saïda in his analysis of early social housing in France, also commenting on the visibility of the reinforced concrete building framing in the blocks and the open-air staircases; as did Minnaert in his most recent biography of Henri Sauvage, pointing specifically to the influence on this site of the architect's first HBM at 7 rue de Trétaigne.[228] The most up-to-date assessment of the complex was undertaken as part of a conservation report commissioned by the *Mairie de Paris* in 2019, covering a sample of historic Parisian HBMs.[229] We are told more about certain specific features of the complex as well as the renovations of a single block that took place in 1984 – Dumont had praised these in her original report on Parisian HBMs which was published in the same year[230] – and then a more contentious and extensive second renovation of the HBM complex in 1993, which apparently attracted much ire from opposers of the proposals, who felt that it failed to take sufficient account of the original building design. Nonetheless, the authors of the 2019 report singled out the fact that the individual blocks had polychrome Bourgogne bricks in either red or yellow with a few ceramic decorations, and concrete coated with cement for the basements.[231]

Chapter summary

The chapter focused on a key societal factor that had an impact on *Belle Époque* urban construction using the novel materials-system: the demand for improved hygiene in urban settings, with its associations in terms of greater affordability and household cleanliness for the working classes, preventing the spread of disease amongst the lower strata of society and its onward transmission to others in a more privileged position. The technical features of the novel materials-system were a useful ally to the commissioners of new urban buildings for the masses, who intended to meet such social needs through derived structural requirements. This could be interpreted as a continued nineteenth-century experiment at the end of the period of the *Belle*

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[227] Eleb, 109. « Les escaliers extérieurs largement ouverts, à structure en béton apparent, donnent accès à un logement à chaque demi-étage ce qui évite la promiscuité et les vues directes sur les logements voisins. La disposition des différents corps de bâtiments, les escaliers ouverts correspondent à l'obsession de l'époque pour la ventilation et l'aération visant notamment à éviter la tuberculose. »
[228] Carbonnier, *Les Premiers Logements Sociaux En France*, 193; Minnaert, *Henri Sauvage*, 82.
[229] DHAAP/DAC, 'Les HBMs: Un Patrimoine Multiple (1894-1949)', 63–68.
[230] Dumont, 'La Fondation Rothschild et Les Premières Habitations à Bon Marché de Paris, 1900-1925', 151.
[231] DHAAP/DAC, 'Les HBMs: Un Patrimoine Multiple (1894-1949)', 63.

Époque that stretched into the early twentieth century; a case study at the end of the chapter examines three historic example HBMs in Brussels and Paris that first employed the new reinforced concrete and cement systems, and all still serving to this day social housing purposes. The HBM at 32 rue Marconi in Brussels, completed in 1902, has a claim to being the first ever HBM to use such as system, though the precise details of which system and how exactly it was employed in the structure are still to be fully determined. The HBM at 7 rue de Trétaigne in Paris completed in 1904 is one of best-known historic examples, partly because of its highly productive architect-team of Henri Sauvage and Charles Sarazin; but even this building was not monolithic in its use of the novel materials-system, again not identifiable. The HBM complex at rue de la Saïda in Paris, for which the first blocks were completed on the eve of the First World War, stands out as a key historic example which had most fully incorporated the monolithic structural features of the *béton armé* system first developed by François Hennebique in the 1890s; it also employed the novel *Compressol* system for its foundation piling that was operated under Hennebique's auspices. Even then, a social housing transition using the novel materials-system only came fully to fruition in France and Belgium after the hiatus of major international conflict.

Chapter 4: Construction actors, professionalism and regulation

Chapter 4 starts by describing the role of building commissioners. The three main *Belle Époque* building design and construction professions, namely those of architect, engineer and contractor are then examined briefly, in terms of how they combined to meet the demand for an emerging role of technical design specialist. The chapter then examines Saint's 'sibling rivalry' relationship between architects and engineers, which is shifted towards 'sibling *cooperation and* rivalry' by emphasising the role of the specialist reinforced concrete and cement systems contractor. The chapter starts to consider the developing nature of the latter's professionalism and outlines the technical education on the novel materials-system available in France for specialist architects and engineers. The regulatory pressures on construction in *Belle Époque* municipalities is examined next, including first European national and local regulations for new reinforced concrete and cement systems. The revised 1902 Paris street regulations are then highlighted in depth, as an easing of centrally-enforced Haussmannian uniformity was sought by architects who espoused new, more adventurous forms of Eclecticism in their building design. The chapter ends by assessing the influence of the regulatory changes on *Belle Époque* building design, and finishes with a case study of Hennebique's monolithic *immeuble* at 1 rue Danton in Paris, completed using his *béton armé* system just before the revisions came into force.

4a. Building commissioners

Outside the construction professionals involved, the historic example buildings in the case studies located in or near the three francophone cities of Paris, Lille and Brussels had a variety of end users. The focus of this part of the chapter is on the individuals or organisations commissioning new French and Belgian buildings that used (in part) novel reinforced concrete and cement systems before the First World War. Table 2.1 lists all thirteen historic example buildings, indicating the commissioners and other actors (where identified) involved in the original construction projects. The table is divided into two categories of commissioner: family businesses and other organisations. Of the first category, three historic example buildings, all in Paris, were each co-owned, co-designed and/or co-constructed by members of the same family business: the *immeuble* at 1 rue Danton (Hennebique); the *immeuble* at 9 rue Claude Chahu (Klein); and the *immeuble* at 185 rue Belliard (the architect Henri Deneux owned and designed the building). Of the second category, three HBMs were commissioned by organisations whose goal was to provide clean and affordable social housing to workers and their families.

Table 2.1: Historic example buildings in the case studies with building commissioners and construction professionals involved

Building (Year Completed)	Commissioners	Architects	Engineers	Contractors
Family businesses				
Bossut-Masurel textile factory warehouse, Roubaix near Lille (1892)	Émile Bossut-Masurel	Unknown	F. Hennebique[232]	Unknown
Charles Six wool-combing mill, Tourcoing near Lille (1897)	Charles Six	Versimée?	F. Hennebique	M. Debosque-Bonte
Extension to *Banque Brunner*, Brussels (1900)	Brunner family	L. Govaerts	F. Hennebique	Unknown
Immeuble, 1 rue Danton, Paris (1900)	François Hennebique	E. Arnaud	F. Hennebique	L. Roquerbe
Immeuble, 9 rue Claude-Chahu, Paris (1903)	William and Charles Klein	C. Klein	F. Hennebique	L. Roquerbe
La Cathédrale, Noisel-sur-Marne near Paris (1908)	Henri Menier	S. Sauvestre	A. Considère, L. Bordenave and Viennot	J. Loup
Immeuble, 185 rue Belliard, Paris (1913)	Henri Deneux	H. Deneux	Unknown	G. Degaine
Other organisations				
Wool-conditioning complex, Roubaix near Lille (1901)	*Chambre de Commerce de Roubaix*	A. Bouvy	L. Coularou	A. Pennel
Annex to *Archives Départementales du Nord*, Lille (1910)	*Département du Nord*	L. Hainez	F. Hennebique	M. Debosque-Bonte
HBM, 32 rue Marconi, Brussels (1902)	*Société anonyme d'habitations à bon marché de l'agglomération Bruxelloise*	L. Govaerts	Unknown	Unknown
Entrepôt Royal B import warehouse, Brussels (1906)	*Société anonyme du Canal et des Installations*	E. van Humbeek	J. Zone & F. Hennebique	L. de Waele

[232] F. Hennebique covers either François Hennebique as the founder of his family business or others who were employed by him.

Building (Year Completed)	Commissioners	Architects	Engineers	Contractors
	maritimes de Bruxelles			
HBM, 7 rue de Trétaigne, Paris (1904)	*Société des logements hygiéniques à bon marché*	H. Sauvage & C. Sarazin	Unknown	Unknown
HBM complex, rue de la Saïda, Paris (1913)	*Groupe des maisons ouvrières*	A. Labussière	F. Hennebique	M. Chaussivert

The first two historic example buildings under family businesses in Table 2.1 were run by Émile Bossut-Maurel (see the case study of the building in Chapter 1) and Charles Six (see the case study of 'daylight factories' in Chapter 2) respectively. They were each leading members of close Catholic families, with many branches, all involved in the major textile industry located in the neighbouring cities of Roubaix and Tourcoing, both near Lille – sadly, both of these buildings have since disappeared together with the industry to which they belonged. These men and their family businesses operated in a highly active manufacturing region, once called the 'Manchester of France', that played a key role in French industrial development during the *Belle Époque* (see the economics of building in Chapter 2) . David Landes, who was later to become a leading economic historian of global industrialisation, referred in the 1970s to "these businessmen [who] were good Catholics by any objective criterion. Yet they were at the same time among the most prosperous and progressive textile manufacturers in the country, so wrapped up in their industry at the expense of other concerns that they became known as the Americans of France."[233] Roubaix-Tourcoing businessmen like Bossut-Masurel and Six had a chip on their shoulder, according to Landes: they resented Lille's central civil administration and national military predominance in their region and so they worked even harder as entrepreneurs to distinguish themselves from their local economic rivals.

It appears that Charles Six was a demanding commissioner for the novel project to construct a new wool combing building on his textile factory complex in Tourcoing using a reinforced concrete system. Hand-written

[233] David Landes, 'Religion and Enterprise: The Case of the French Textile Industry', in *Enterprise and Entrepreneurs in Nineteenth- and Twentieth-Century France*, ed. Edward C. Carter II, Robert Forster, and Joseph N. Moody (The John Hopkins University Press, 1976), 43.

correspondence between Six and the local Hennebique *concessionnaire* Debosque-Bonte, held at the CAAC (BAH 076 Ifa 3540/12), shows us that he regularly contested the speed and quality of construction, seeking financial compensation from the contractor and the Hennebique enterprise for the inconvenience caused. In one letter, Charles Six makes it clear how delays in finishing off the building, which appears to have weakened structurally during the construction process due to a combination of poor weather and unsatisfactory workmanship, had had a serious impact on his business:

> You are causing me enormous harm, you owe me reparations ... You have ruined my business and the negative effect produced on my clientele may not be repairable for the future, because I can make no commitments to new contracts.[234]

As already seen in the case study of 'daylight factories' in Chapter 2, Henri Menier ran a highly successful chocolate enterprise at Noisiel-sur-Marne on the edges of Paris and expanded these to major manufacturing premises that are all still with us today, though no longer operational. The history of the company's operations and site provides further insight into the commissioning context for the new cocoa and sugar processing building, *La Cathédrale*, completed in 1908:

> Named "the world's first chocolate company" at the Universal Exhibition in Chicago in 1893, the factory underwent new transformations … The increase in chocolate production, which now stood at 12 million kg per year, had itself necessitated a technical and spatial reorganization marked, in particular, by the construction of new buildings for the processing of raw materials.[235]

La Cathédrale was commissioned by Henri Menier as the head of the family business, but with advice from his chief engineer Bordenave; in effect its end users were his many employees who operated the machinery within the cocoa and sugar processing building, and then scuttled back and forth to collect and then deliver the produce across the *passerelle* that linked its island over the river to the rest of the chocolate

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[234] « Vous me causez un énorme préjudice, vous me devez une réparation … vous ruinez ma maison et l'effet négative produit sur ma clientèle, ne sera peut-être plus réparable pour l'avenir, car pour les nouvelles affaires je ne puis prendre aucun engagement. »

[235] Cartier, Jantzen, and Michel, *Noisiel, La Chocolaterie Menier Seine-et-Marne*, 11,14. « Consacrée "première chocolaterie du monde" à l'occasion de l'Exposition Universelle de Chicago en 1893, l'usine seine-et marnaise connaît de nouvelles transformations … L'accroissement de la production chocolatière qui atteint dorénavant 12 millions de kg par an, a lui-même nécessité une réorganisation technique et spatiale marquée notamment, par la construction de nouveaux bâtiments pour le traitement des matières premières. »

manufacturing complex. However, there was a whole other intended group of final end users of the product being manufactured by these busy workers. These were well-off Parisians, French elite and international visitors who were encouraged to come and appreciate the internal and external beauty of the building and the factory, and most importantly tell the world how fantastic Menier chocolate was – not just in the final eating of it, but in the appreciation of the clean and efficient manufacturing process used to produce it. A similar back story can be applied to all types of building that have been, and continue to be, constructed by the main professionals involved. Hence, an important aspect of the societal context for *Belle Époque* construction using the novel materials-system was the role of the three professions most linked to the design and construction of buildings: the architect, the civil engineer and the contractor.

4b. Technical design and construction specialists

Outside the commissioners of buildings, those skilled people involved in an actual construction project were conveniently sub-divided into groups according to the type and level of their expertise, and such groups then acquired their own independent identities as societal structures once they achieved a minimum membership threshold: we have known them as the broad professions of architect, engineer and contractor, or even more commonly 'builder' in the last case, which has lumped together all types of on- and off-site construction worker, whatever the nature and level of skills they possess. Engineers involved in construction have had their own flavours depending on specific technical requirements – a civil engineer (derived from military engineer) as a generalist who was theoretically capable of handling a multitude of different types of construction project from the smallest to the largest – whereas the emerging profession of structural engineer would only specialise in niche fields connected to a specific material or type of structure.

The Swiss educator of civil engineers Hans Straub noted in his textbook how during the eighteenth century the Comte de Buffon tested iron rods and wooden beams of varying dimensions, recording their sagging properties before rupture; there were also efforts to prevent cracks widening in St Peter's dome in the Vatican, leading to the famous 1743 report of the three French mathematicians le Seur, Jacquier and Boscowich.[236] This last was a ground-breaking approach using science and research for structural engineering solutions, providing proof of the early use of quantitative statics. The nineteenth-century Frenchman Louis

[236] Straub, *A History of Civil Engineering: An Outline from Ancient to Modern Times*, 109, 111–16.

Navier had a significant impact on the science of structural analysis, including the theory of flexure, buckling problems, and the systematic solution of statistically indeterminate problems. All these and many other described developments within an emerging structural engineering context, put *Belle Époque* architects in a defensive mode vis-à-vis their main 'opposing' profession.[237]

The role of the technical design specialist became more pivotal in building construction as the nineteenth century progressed and the range of urban construction techniques developed beyond traditional timber, masonry and brick. From a British perspective, the introduction of first steel and then reinforced concrete framing required specialist construction contractors like the American Sven Bylander, engineer for the Ritz Hotel (1905) and Selfridges department store (1909) in London.[238] In France, the first nineteenth-century iron structures in towns and cities no doubt contributed to the change. The most significant visible statement of this was a major national project that required an untried team of architect, engineer **and** contractor to operate effectively under extreme time pressure - this was the design and construction of the steel and glass *Galerie des Machines* in Paris in 1889 (see more on this unique structure in Chapter 5).

Saint has brought together different strands of academic thought on the 'rival sibling' relationship between architect and engineer, particularly during the nineteenth and twentieth centuries.[239] He identified past opportunities for cooperation between the two professions, stressing areas such as the building of railway bridges and stations, where an architect's professional skills were better at addressing 'architectural dignity' and 'variety in rooms and scale' than those of an engineer.[240] Saint also noted that Straub had first attributed the nineteenth-century transition between the two disciplines to the arrival of new materials such as iron and steel, and the triumph of structural rationalism. The Swiss advocate of International Modernist architecture, Sigfried Giedion, had previously broached this topic in his 1938-9 Harvard University lectures published from 1941 onwards.[241] In a section on the transition from iron column to steel frame, Giedion, like his fellow International Modernist Le Corbusier before him, gave much importance to the rise of industrialised

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[237] Straub, 152–53.
[238] Jeanne Catherine Lawrence, 'Steel Frame Architecture versus the London Building Regulations: Selfridges, the Ritz, and American Technology', *Construction History* 6 (1990): 26–27.
[239] Saint, 'Architect and Engineer: A Study in Construction History'; Saint, *Architect and Engineer: A Study in Sibling Rivalry*.
[240] Saint, *Architect and Engineer: A Study in Sibling Rivalry*, 489.
[241] Siegfried Giedion, *Space, Time and Architecture. The Growth of a New Tradition.*, 5th ed. (Harvard University Press, 1982).

production from the late eighteenth century. The development saw a schism between architect and engineer which was evident in the new metallic technical developments in construction – according to Giedion, this was wilfully ignored by nineteenth century architects, who attempted to clothe the new materials in 'false fronts'.[242]

Saint focused, like Addis, on the emergence of structural engineering as a construction specialism, to which other disciplines had to respond. Saint singled out engineer-historian David Billington for championing an appreciation of 'engineering-art', that is, technical design as an art-form completely distinct from architecture.[243] By contrast, historian of technology Tom Peters sees this only as a different way of defining art, with his own interest lying in different types of shared building design thinking across professions.[244] Saint compromised between these two different perspectives on technical design in an effort to keep both together under the same umbrella; he therefore concluded his book by warning structural engineers not to stray too far into the realm of 'architecture-art', for if they did so they might devalue their own discipline-specific, technical contribution to building design.[245] Saint's assertion is reasonable, though inevitably connected to the delineation of specialist professional boundaries: he highlighted the emergence of the consulting civil and structural engineer towards the end of the nineteenth century, which bridged the engineer-contractor relationship. Hence, later in the next century, structural engineers such as Pier Luigi Nervi and Ove Arup had their own architectural construction partners with whom they worked almost symbiotically.[246]

There were in fact three, not two, sibling professions, occasionally combined into a single person or organisation during the *Belle Époque* (much more so nowadays), but *all* involved in building design and construction. Saint acknowledged the unique relationship between architect, engineer and contractor typified by the multi-talented Perret brothers in early twentieth-century France – their significant *immeuble* at 25b rue Benjamin Franklin in Paris (completed in 1904), while not included in the thirteen historic example buildings in the case studies, is examined extensively in Chapter 6 in an application of the historical mechanism produced

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[242] Giedion, 182–83.
[243] David Billington, *The Art of Structural Design: A Swiss Legacy* (Princeton University, 2003); Saint, *Architect and Engineer: A Study in Sibling Rivalry*, 315, 491–92.
[244] Tom F. Peters, 'How the Introduction of Iron in Construction Changed and Developed Thought Patterns in Design', in *Before Steel. The Introduction of Structural Iron and Its Consequences* (Sulgen/Zurich: Verlag Niggli AG, 2010).
[245] Saint, *Architect and Engineer: A Study in Sibling Rivalry*, 492.
[246] Saint, 490.

in this thesis.[247] The brothers Auguste (1874-1954), Gustave (1876-1952) and Claude Perret are a fascinating example of the crossover between the three distinct professions, hence their interest to many researchers of *Belle Époque* architecture.[248] The first two were the talented architecturally-trained sons of a building contractor father, at least one of whom had a solid grasp of structural engineering. Both had studied architectural theory, Auguste winning prizes at the École des Beaux Arts, but their collective interests became more aligned with the application of a novel materials-system to a designed and finished urban building, whether monumental or not. What if any initial conclusions can one draw from the extensive biographical and other analyses of Auguste Perret, as well as from his contemporaries, about the role of *Belle Époque* contractors as emerging technical design specialists in the use of reinforced concrete and cement systems in buildings?

The first point of note is that the broadening employment of new reinforced concrete and cement systems for urban buildings gave specialist contractors a technical 'foot in the door', from which they could then leverage a wider clientele in their principal localities and further afield. Many specialist contractors acted as local agents for Hennebique and the other inventors of the novel materials-system, and eventually developed their own independent design understanding beyond using without question the technical information provided to them. Delhumeau has described fully how Hennebique, at least initially, organised and codified key technical tasks by circulating notes with ready-made formulas, tables and calculations about the *béton armé* system to his expanding network of regional representatives – this aligns well with the concept of structural specifications considered in Chapter 1, and collectively constituted a precise enough set of instructions to reassure contractors, who would be legally liable for the correct implementation of Hennebique's system. In this way the fate of the *béton armé* system was linked to the quality and care taken in the execution of building work that employed it, "in order to limit the risks of faulty workmanship, and in order to simplify operations … Hennebique felt the value of this by carefully inspecting most of his early construction sites

[247] Saint, 231–42.
[248] See for example in Collins, *Concrete. The Vision of a New Architecture*; Joseph Abram, 'Perret et l'école Du Classicisme Structurel (1910-1960)' (Ecole Nationale Superieure d'architecture de Nancy, 1985); Karla Britton, 'Auguste Perret' (Harvard University, 1997); Joseph Abram, *Auguste Perret*, 2nd ed. (Editions du Patrimoine, 2013).

himself."[249] Original archival files include a list by Hennebique's Lille agent, Mottez, of the final bids for the construction of the Annex to the *Archives Départementales du Nord* (see the case study of four buildings in a new urban design approach in Chapter 5). The list gives a flavour of the contracting market for this type of work at the time, including as it did a selection of well-known Hennebique *concessionnaires*, including Debosque-Bonte who had completed the Six wool-combing mill in nearby Tourcoing (see the case study of 'daylight factories' in Chapter 2). There were other familiar reinforced concrete systems proposed, but it would appear that the odds may have been stacked in Hennebique's favour as many of the bidders planned to use his system; it seems curious that Debosque-Bonte should have won on price by only a 0.05% extra discount over the second-placed contractor Rouzé, who used a system linked to the Ghent contracting firm of Grondel Frères.[250] However, a letter in the same files from Debosque-Bonte to Hennebique indicates that he had been aware of the 25% discount, perhaps through friendly sources in the local administration, if not the Chief Architect Hainez himself.

There appears, therefore, to be a reasonable case for stating even more clearly that specialist contractors for early reinforced concrete and cement systems developed a quasi-professional status of their own. This may not have been as formalised as the established groups of alumni from architectural and engineering schools (see below), but it could still provide a useful function within the wider set of those with sufficient technical knowledge to use novel reinforced concrete and cement systems effectively in their design of buildings. This issue will be explored further within the context of using the historical mechanism to describe the design and construction of the *immeuble* at 25b rue Benjamin Franklin in Chapter 6.

4c. Technical building design education

While many architects and civil engineers were trained in building theory at often elite technical and artistic schools, in the case of the majority of contractors, with some notable exceptions, they learned 'by doing' through traditional master-apprentice methods. This educational process helped shape the relationship

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[249] « … de manière à circonscrire les risques de malfaçon, et afin de simplifier les operations … Hennebique en éprouve la valeur en inspectant lui-même avec attention la plupart de ses premiers chantiers. » Delhumeau, *L'invention Du Béton Armé : Hennebique, 1890-1914*, 68–69.

[250] Perhaps it was a national bias of some kind? Hellebois references Grondel Frères a number of times in her doctoral thesis on early Belgian reinforced concrete structures, but with no mention of a specific system used other than one designed independently by Paul Christophe for a Belgian water tower project of around the same time. Hellebois, 'Theoretical and Experimental Studies on Early Reinforced Concrete Structures', 177, 250.

between the three professions, of which the 'sibling rivalry' between architecture and civil engineering has received the most in-depth historical analysis; though, as we have seen earlier in the chapter, there would seem to be a growing case for expanding the term to 'sibling cooperation and rivalry', since this better illustrates the contrasting yet complimentary approaches between the three corpuses of building design and construction expertise.

The *École des Beaux Arts* (EBA) in Paris was the predominant nineteenth-century arts and architecture school, not just for French and Belgian architects but for a worldwide cohort, including and in particular North Americans. It was closely connected to the French *Académie des Beaux Arts*, which represented both elite artists and their wealthy patrons, most significant of whom was Napoleon III until his forced departure in 1870. The Third Republic might have democratised French politics, but from a cultural perspective it was, to start at least, still traditional in its tastes. There were competitor schools which had emerged during the nineteenth century for those who wished to practice as construction professionals in France, not least the *École Centrale des Arts et Manufactures*. This institution had promoted its independence from the fine arts hierarchy of the EBA, as well as the importance of metallic structural approaches to construction. All of this started to influence a prevailing ethos of classical architecture and accompanying state-led training originating during the preceding centuries. [251] With the re-emergence of concrete and cement from the mid-nineteenth century in France as accepted building materials, after a lengthy hiatus since their extensive use in Roman times, courses for architecture and engineering students began to adapt to the use of new materials.

The *École des Ponts et Chaussées* (EPC) was the leading national school for French civil engineers, producing its own specialist courses on the new materials and systems; one for the scholastic year 1913-14 still held in the school's archives was given by Professor Augustin Mesnager (1862-1933), *Ingénieur en Chef* at EPC, which lists key calculations and formulae to be absorbed by students.[252] Mesnager had undertaken tests for Armand Considère, an EPC graduate who as already seen in Chapter 1 was the inventor of the *béton fretté* system and heavily involved in the work of the 1901-5 French Commission on reinforced cement. Considère also authored

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[251] For more on the relationship between the École Centrale and the EBA and the technical influence of the former see: Tom F. Peters, 'Education at the École Centrale in Paris and Its Influence on the Creation of Modern Iron Construction', in *History of Construction Cultures - Proceedings of the 7th International Congress on Construction History, 7ICCH 2021*, vol. 2 (CRC Press/Balkema, 2022), 645–49.

[252] Augustin Mesnager, *Cours de Matériaux de Construction En Constructions En Béton Armé* (École des Ponts et Chaussées, 1914).

a book on the novel materials-system, which was translated into English and published in 1906 as a second edition in the USA.[253] He set out his stall to those of his Anglo-Saxon readers who may have doubted the value of learning more about the new reinforced concrete and cement systems. Considère emphasised that the first attempts to embed iron rods into concrete were undertaken by practical men rather than theorists, who he suggested would never have recommended such a combination of materials for which they had little scientific confidence:

> … engineers in charge of great public and private works, with some few exceptions, have hesitated to adopt the new material on a larger scale. They thought that a clearer and fuller knowledge must first be obtained of the phenomena resulting from the combination of concrete and steel and of its probable durability and resistance to atmospheric influences.[254]

Belhoste's contribution on early engineering and architectural education in reinforced concrete and cement acknowledges the key physical relationship between concrete and metal that needed to be taught to a new generation of technical design specialists – that of similar coefficients of elasticity for each material:

> The low tensile strength of concrete, however, introduced a limitation detrimental to its use. If it found a powerful application in foundations or the manufacture of beams and columns working in compression, it could not be used for all elements working in tension. The idea therefore came quite naturally to reinforce it with a metal frame, taking advantage of the providential fact that the two materials had very comparable coefficients of expansion, and complementary mechanical behaviors.[255]

The first evidence of an architecture course which specifically included teaching about reinforced concrete and cement systems was one begun in 1895 at the École Centrale, most probably run by the architect Fernand

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[253] Armand Considère, *Experimental Researches on Reinforced Concrete*, 2nd ed. (McGraw Publishing Company, 1906). The translator of Considère's book was the American civil engineer Leon Moissieff, who would later suffer the embarrassment of constructing the infamous Tacoma Narrows Suspension Bridge or 'Galloping Gertie'; it collapsed spectacularly four months after completion in 1940 due to key design failures which ruined Moissieff's subsequent career.
[254] Considère, 1.
[255] Jean-François Belhoste, 'Les Debuts Du Béton Armé et Son Introduction Dans Les Écoles d'ingénieurs et d'architecture', in *Le Béton Armé. Histoire d'une Technique et Sauvegarde Du 20ème Siècle*, ed. Matteo Porrino (Infolio, 2019), 59. « La faible résistance du béton à la traction introduisait cependant une limitation préjudiciable à son utilisation. S'il trouvait une application performante dans des fondations ou la confection de poutres et poteaux travaillant en compression, il ne pouvait être employé pour tous les éléments travaillant en traction. L'idée vint donc assez naturellement de le renforcer par des armatures métalliques, en profitant du fait providentiel que les deux matériaux avaient des coefficients de dilatation très comparables, et des comportements mécaniques complémentaires. »

Delmas (1852-1933); he had designed an early Hennebique roof in a factory which was never actually built, as well as the new headquarters of the *Société des Ingénieurs Civils* which was constructed at rue Blanche, Paris in 1896 using elements of both the *béton armé* and Coignet systems.[256]

4d. The regulatory aspects of construction

Early industrial standards for innovative reinforced concrete and cement systems, principally in the form of industrial patents and to a lesser extent structural specifications and technical guidance, were examined in Chapter 1. The chapter showed how in France and Belgium the 1906 voluntary national technical guidance for the novel materials-system only applied to those contractors undertaking state-commissioned civil engineering projects. By contrast, the analysis in this part of Chapter 4 covers compulsory municipal legislation related to the construction of buildings during the *Belle Époque*, with the focus on post-Haussmannian Paris.

Compulsory building and planning regulations have been developed globally by urban authorities – they are legally-tested benchmarks for compliance by individuals and companies, hence they are clearly *not* voluntary measures like technical guidance. While regulations may have been one end destination for codified technical knowledge about novel materials-systems, they have had their own discernible influence on the development of technical design. Making such rules in the French Third Republic implied a political context since the appropriate laws needed to be passed, after debate, by elected representatives of the people; they were in turn informed and influenced in this process by special interest groups. Angelino has argued that modern day stakeholders may contribute negatively to the development of a construction design standard due to their political interests:

> If there is too much influence from [legal and industry] experts, the codes may become difficult to use (difficult to understand, difficult to build, etc.). If there is too much influence from a manufacturing segment, the codes may result in unfair competition or may not adequately protect people.[257]

In this same context, if a construction design standard appears to satisfy completely the needs of statutory regulations, this might have an unfortunate side effect in making users less willing to apply alternative approaches. So over-regulation can stifle construction innovation. Bertels and de Jonge had concluded their

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[256] Belhoste, 65.
[257] Angelino, 'Developing Better Design Standards for the Construction Industry', 114.

paper on Belgian state construction procurement (considered under structural specifications in Chapter 1) with an observation on the historical role of municipal regulation, that building specifications are strongly normative in nature:

> Hence, they reveal an 'ideal' building process and try to regulate those aspects of building that are hard to regulate in practice. Therefore, it is important to confront the results of their analysis with sources that expose how these rules and guidelines were put in practice and which tensions and conflicts arose between theory and practice.[258]

Even though German engineer Matthias Koenen had outlined a design theory for reinforced concrete in 1886 and the *Monier-Broschure* had been published in 1887 by the specialist operator Wayss, reinforced concrete was not mentioned at all in a new Berlin public building law of ten years later. Action did finally take place at the turn of the century in response to the collapse of the hotel "Zum Bären" in Basel, due to poor employment of the *béton armé* system, causing a public discussion about the reliability of reinforced concrete. As a result, the German cities of Hamburg, Düsseldorf, Dresden and Frankfurt published in 1903 local provisions for the novel materials-system, but with limited scopes. The first general regulations that specifically addressed high-rise reinforced concrete structures were published by the Prussian minister of Public Works in 1904.[259] Switzerland had been the first state to produce national guidance for reinforced concrete and cement, after the *Swiss Engineer and Architect Society* published new technical provisions in January 1904, three months before the new Prussian regulations appeared; however, this Swiss guidance was only incorporated into national regulations in 1909, despite what would seem to have been a pressing need for an official response to the Basel hotel disaster of eight years previously.[260] Hennebique's very active Swiss agent, Samuel de Mollins, had managed to persuade authorities in Lausanne, Geneva, Zurich, Basel and St Gallen in 1895 to approve his use of the *béton armé* for building construction in those cities alone.[261] A pattern of isolated regulatory change principally at an individual municipal or at most provincial level appears common throughout Europe, including

[258] Bertels and Jonge, 'Building Specifications and the Growing Standardizing of Public Regulation in Nineteenth-Century Belgium', 203.
[259] Voorde, Kuban, and Yeomans, 'Early Regulations and Guidelines on Reinforced Concrete in Europe (1900-1950). Towards an International Comparison.', 3–4. The authors noted that the new Prussian building regulations for reinforced concrete were not enforced in other parts of the German Empire, but there was a voluntary willingness to imitate the industrial standards to which they referred.
[260] Voorde, Kuban, and Yeomans, 2–3.
[261] Hans-Ulrich Jost, 'The Introduction of Reinforced Concrete in Switzerland (1890 to 1914): Social and Cultural Aspects', in *Proceedings of the Second International Congress on Construction History Vol 2*, ed. J. W. P. Campbell (Construction History Society, 2006), 1742.

in France and Belgium – the difference being that the capital cities as centres of national political power and representation had a greater influence on the rest of the nation; and those responsible for introducing any regulatory reforms were prepared to learn from competing national capitals, rather than from less significant or more independent municipalities. This certainly applied to the Parisian revisions to street regulations.

Yeomans has examined a range of post-1900 British construction materials, and within this covered some mainly technical aspects of British building regulations.[262] Of more direct relevance, Harper's doctoral thesis on the evolution of English building regulations between 1840-1914 had already suggested that these developed due to a wide range of factors, including many of those covered in Section 1 under technical guidance as well as the societal ones already examined in this Section[263]:

- the growth of the towns;
- the increase in building in urban areas;
- the dangers to public health and safety;
- various political factors;
- the nature of the building industry;
- new developments in building including new types of building, new materials, structure and services;
- the effect of building disasters;
- influences from abroad, the professions, changes in architectural styles, and building journals and other publications; and
- advances in scientific understanding of construction.

Harper had used two examples of a more scientific approach to building regulations in Britain before the First World War, one related to the increasing role of engineers as novel materials-systems were introduced, the other to the work of the British Fire Prevention Committee. The results of the latter's tests on doors under fire conditions at their Fire Testing Station in Bayswater in 1899, revealed what Harper saw as "alarming

[262] Yeomans, *Construction Since 1900: Materials*, 28–31.
[263] Roger Henley Harper, 'The Evolution of The English Building Regulations 1840-1914' (University of Sheffield, 1978).

misconceptions which had been incorporated in the London Building Act of 1894, and led to their correction in the amendment Act of 1905."[264] Harper however concluded that any direct correlation between changes in architectural style and changes in English building regulations in the nineteenth century were difficult to define precisely. He provided an example from the 1894 London Building Act, about clauses to allow a greater use of oriel and bay windows in urban buildings in response to the return of the Queen Anne style after 1880 – this will be covered in the part of this chapter on the revised Parisian street regulations of 1902. Harper therefore decided that any possible relationship was one-way only, at least in England, because many architects saw such municipal regulatory control as a clear threat to their creative design freedoms – he saw a parallel with the movement in the profession that had objected to any form of examination of architectural design:

> Many, and particularly those who supported Norman Shaw and Thomas Jackson in their memorial "Architecture, a Profession or an Art" of 1892, would have felt the same way about the danger of aesthetic assessment in both architectural examination and building regulation.[265]

Muthesius included the emergence of nineteenth-century building regulations in his thorough analysis of the developing architectural typology of the English terraced house.[266] He connected this with the growing standardisation of urban construction approaches within the typology, in turn pushed by economic factors. Muthesius picked up on the use in building specifications as a means of standardising legal obligations, of direct references to prevailing building regulations; he also referenced the controlling influence of model urban colonies created by textile manufacturing giants such as Sir Titus Salt in Yorkshire, which paralleled events in France described in Chapter 3.[267]

As part of her doctoral thesis and subsequent book, Slaton looked at regulations related specifically to the use of novel reinforced concrete systems in 1900-1930 American factories.[268] Her thread of thinking centred very much on the role of American materials and systems testers who were seeded within the construction industry as university graduates with a sufficient professional status, and hence they could credibly act as knowledge brokers between academic expertise and contracting practice. The academic credentials were displayed

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[264] Harper, 573.
[265] Harper, 578.
[266] Stefan Muthesius, *The English Terraced House* (Yale University Press, 1982), 33–37.
[267] Muthesius, 36.
[268] Slaton, 'Origins of a Modern Form: The Reinforced-Concrete Factory Building in America, 1900-1930'; Slaton, *Reinforced Concrete and the Modernization of American Building, 1900–1930*.

through published treatises and membership of expanding industrial standards committees, through which compulsory regulations first emerged for the novel materials-system in America. Subsequently, Friedman investigated the impact of New York building codes on the steel skeletons of skyscrapers in the city at the end of the nineteenth century.[269] Returning across the Atlantic to Europe, Puget later examined the rules and practices relating to the construction of private buildings in Aix-en-Provence and Marseilles in the mid-17th century.[270] He investigated evidence of inspections to verify that builders respected the terms of their permits for construction, as well as new regulations on public law and order that were being issued. However, this was two centuries prior to significant changes to Parisian regulations that were to facilitate a potentially new technical design environment for *Belle Époque* buildings. Clarke noted that, despite being adopted throughout most parts of England for construction using novel reinforced concrete systems, the 1915 London County Council regulations quickly proved too restrictive for local industry; reinforced concrete skeletons in fact became more expensive for many types of office structure, so discouraging the use of the new systems. Clarke makes an analogy with the London steel regulations of six years earlier, where the allowable stresses and loads were also extremely conservative, though this fact seemed to hold back development less than for reinforced concrete systems. In both cases, many London engineers and contractors learned quickly how to use the new approaches and so became frustrated with the municipal restrictions.[271] But even well into the 1920s, the use of reinforced concrete systems remained relatively rare in London compared with steel, the opposite of the post-war trend in France and Belgium. Finally, in terms of a general overview of the specialist literature, an academic paper by Zheng and Campbell looked at the role reinforced concrete systems played in the modernization of Chinese architecture by 1914, when the Shanghai Municipal Council of the International Settlement began to formulate regulations for the new materials-system.[272]

[269] Donald Friedman, ‘Building Code Enforced Evolution in Early Skeleton Buildings’, in *Proceedings of the Second International Congress on Construction History, Vol. 2*, ed. J. W. P. Campbell (Construction History Society, 2006), 1171–87.
[270] Julien Puget, ‘Construction Market Organization in the 17th Century: Norms, Actors and Practices Examples of Extension Plans in Aix and Marseille.’, in *Nuts and Bolts of Construction History. Proceedings of the Fourth International Congress of Construction History*, ed. R. Carvais et al. (Editions Picard, 2012), 495–502.
[271] Jonathan Clarke, ‘The Development of the Speculative Office in Inter-War England’ (University of Cambridge, 2021), 165.
[272] H. Zheng and J. W. P. Campbell, ‘History of Early Reinforced Concrete in Modern Shanghai, 1890-1914’, *Construction History* 36, no. 2 (2021): 81–122.

Municipal regulation in Belle Époque Paris

Legault notes the impact of a revision of Paris building regulations allowing the construction of exterior walls of less than 50 cm width, that coincided with the 1878 *Exposition Universelle*, when exposed iron building framing was used with brick infills. While interesting in terms of extending the use of metallic construction systems in response to the demands of Viollet-le-Duc and other Rationalist designers, the focus of this part of the thesis starts from the end of the 1880s, hence the analysis is limited to Parisian regulatory changes during the later period of the *Belle Époque*.[273] 1882, 1884, 1902 and 1904 were years that saw key changes to the Paris city hygiene and street regulations, with the authorities gradually adjusting the strict conforming regime set in the Haussmann era prior to the start of the Third Republic in 1870. Of these changes the key 1902 decree on Paris streets was an attempt to consolidate previous liberalising measures. Gillet saw these revised regulations as providing architects with new architectural freedoms, particularly in terms of novel tectonic and decorative approaches to their works using the new materials-systems.[274] We will see later in this chapter that there are other views about the overall impact of the changes to the regulations, and it seems clear that such gained freedoms would always be limited by other external constraints such as location, cost and prevailing taste. But we first need to understand better the proposed and enacted changes.

Over the course of five months spanning 1902-3 the weekly magazine of the *Société Centrale des Architectes Français (L'Architecture)* published a series of pieces reporting on a two-day October 1902 conference organised by Louis Bonnier.[275] Bonnier was a leading Parisian *Architecte-Voyer* who had managed to bridge between the city authorities, for whom he worked, and the more innovative building designers of his era[276]. Recounted in 14 issues, Bonnier first described the context for changes to the city's *règlements de voirie*

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[273] Legault, 'L'Appareil de L'Architecture Moderne: New Materials and Architectural Modernity in France, 1889-1934', 28.
[274] Gillet, 'Conception et Confection. Une Histoire Matérielle Du Revêtement Céramique Des Immeubles Parisiens (1900-1914)', 104.
[275] Louis Bonnier, 'Les Nouveaux Règlements de Voirie a Paris', *L'Architecture* 15, no. 35, 47–50, 52 (1902); Louis Bonnier, 'Les Nouveaux Règlements de Voirie a Paris', *L'Architecture* 16, no. 1–4, 6–8, 10, 12 (1903).
[276] Bonnier was a remarkable man born in small rural town near Lille in 1856, who studied architecture at night school and at the *École des Beaux Arts* in Paris while employed by the city authorities. He was considered a leading proponent of the *Art Nouveau* architectural genre of Eclecticism in France, having redesigned the *Salon de l'Art nouveau Bing* in Paris in 1895. He served as president of the *Société des architectes diplômés par le gouvernement* (SADG) from 1901 to 1910 (with two one-year pauses). He was also an active corresponding member of RIBA. In February 1914 Bonnier was appointed *inspecteur général des services techniques d'architecture et d'esthétique et de l'extension de Paris*. Mathilde Dion and Bernard Marrey, 'Louis Bonnier (1856-1946) Notices Biographiques' (Centre d'archives d'architecture du XXe siècle, n.d.).

(street regulations) authorised by the French Government on 13 August 1902 and published in an edition of the journal at the end of the same month. He then went on to explain all 45 articles of the new law, which he pointed out to his audience were far fewer than the replaced 79 articles within the combined 1882 and 1884 regulations. *L'Architecture* had previously published in April 1897 interim sketches by Bonnier of the expected impact of proposed changes (Figure 2.8), but it had taken another five years for the full process to be completed.[277] The 1882 decree embodied the first changes made during the Third Republic and had tried to balance a move for greater expressive freedoms against restricting hygiene requirements in the French capital. However their scope was necessarily limited to projections from buildings into streets that were becoming more popular, with new bay windows imitating a growing British trend.

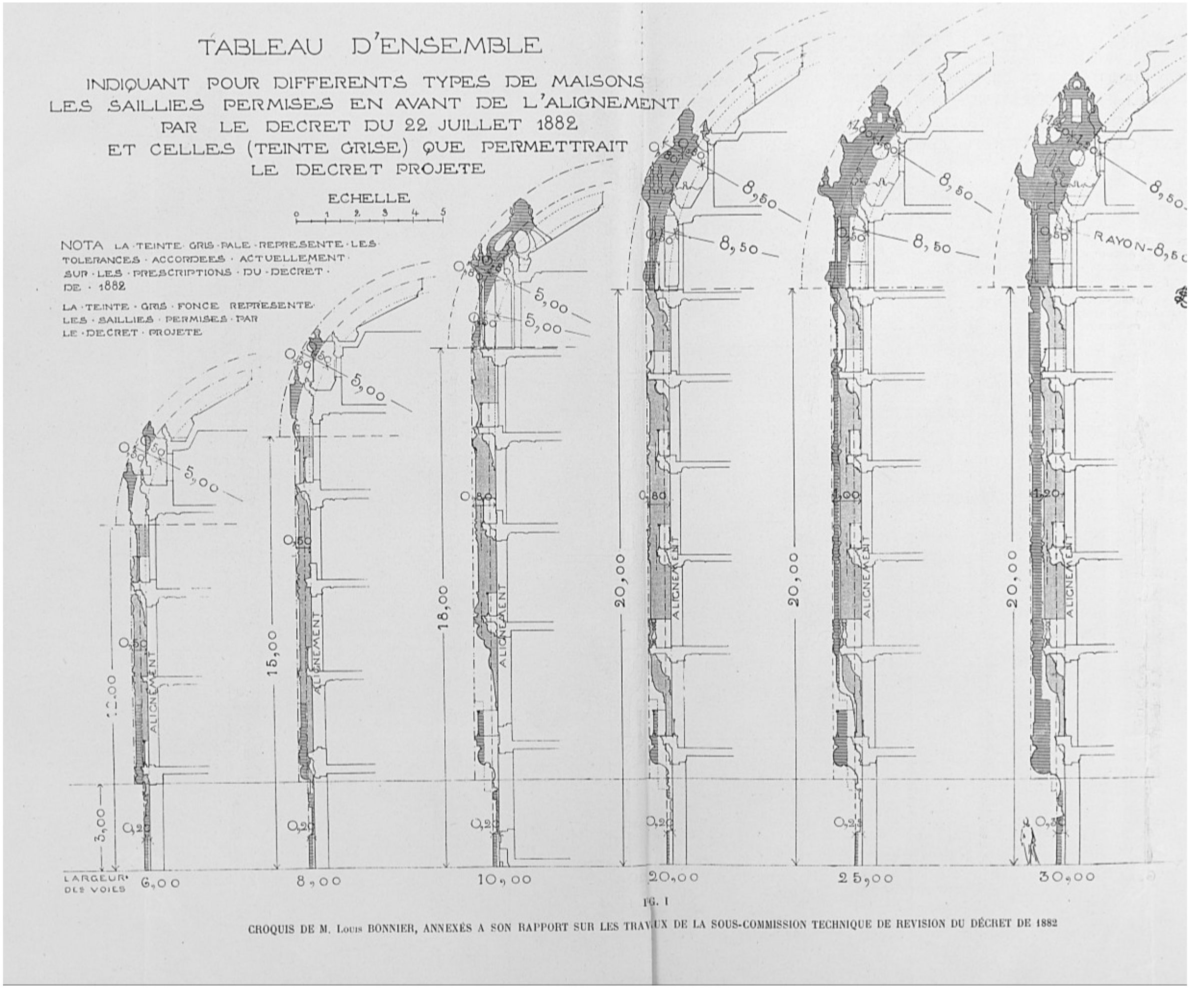

Figure 2.8: Louis Bonnier sketch comparing the 1882 Parisian rules for street projections with proposed revisions in 1897 which are shaded in a darker grey. (L'Architecture, Vol. 10, No. 14, 1897, plates)

277 'La Revision Du Décret Du 22 Juillet 1882 Sur Les Saillies à Paris', *L'Architecture* 10, no. 14 (April 1897): 113–14.

The 1884 amendments attempted to extend the scope of the 1882 changes, this time to cover unsatisfactory regulations about the width of streets and heights of facades, as well as the dimensions of internal and shared courtyards. Bonnier used the words of a respected colleague on the Paris regulation commission's technical committee, the architect Louis-Charles Boileau[278], to summarise the poor state of affairs as they had witnessed them at the end of the 1890s – Boileau had stressed the ubiquity of the *maison de rapport* in the French capital because of the high price of land, as well as the monotony of street facades due to the regulatory restrictions. He therefore proposed a solution:

> In our opinion, it would suffice, as regards heights, to abandon the four arbitrary devices of 1884, to refer to a system of proportionality in harmony with, as exactly as possible, the different widths of the streets. This system would give rise to a fairly considerable number of devices that would force architects to find different and relatively unforeseen solutions. Art would gain as much as hygiene.[279]

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Bonnier did not refer to subsequent 1893 changes to regulations, probably because they were equally unsatisfactory and focused purely on the increasing use of bay windows. As to the new regulations announced in the summer of 1902, Bonnier delved into each of the 45 new articles, providing guidance and examples to the conference delegates and subsequent wider readership. He began by laying out the general aim of the new legislation which echoed aspects of Boileau's earlier statement:

> You now know the intentions of its drafters, intentions which consist, on the one hand, in establishing a fairer proportionality between the needs of construction and the general interest, and, on the other hand, in a better interpretation of the laws of hygiene.[280]

Looking at some of the articles in more depth:

- *Article 1* confirmed that no new private building (unless it was exempted from the regulations for reasons of monumentality, art, science or industry) could have a facade height greater than 20m. This

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[278] Boileau was editor of *L'Architecture*, which explains why the journal published the conference proceedings.
[279] Bonnier, 'Les Nouveaux Règlements de Voirie a Paris', 1902, 458. « Il suffirait, à notre avis, en ce qui concerne les hauteurs d'abandonner les quatre dispositifs arbitraires de 1884, pour s'en référer à un système de proportionnalités concordant, aussi exactement que possible, avec les différentes largeurs des rues. Ce système donnerait lieu à un nombre assez considérable de dispositifs qui obligeraient les architectes à trouver des solutions différentes et relativement imprévues. L'art y gagnerait autant que l'hygiène."
[280] Bonnier, 'Les Nouveaux Règlements de Voirie a Paris', 1903, 58. « Vous connaissez maintenant les intentions de ses rédacteurs, intentions qui consistent, d'une part, dans l'établissement d'une proportionnalité plus équitable entre les besoins de la construction et l'intérêt général, et, d'autre part, dans une meilleure interprétation des lois de l'hygiène. »

clearly placed Paris, like most other European cities of the time, in a completely different setting from the city of Chicago across the Atlantic, where iron- and then steel-framed 'skyscrapers' had been ascending ever more upwards since the 1880s, admittedly in special local circumstances that were gradually duplicated by other American cities.[281]

- *Article 3* provided new calculations for the part of the *gabarit* (profile) describing the tapered shape of the mansard-roof of Parisian buildings above the facade height limit set by the width of the street; with a key hygiene goal of permitting a healthy cushion of air to sit above any accommodation included under the roof to maximise occupancy for the whole building.
- *Articles 7 and 8* provided incentives for constructors to build back from the street, as they would then be allowed even more freedom to exceed the limits of the *gabarit* described in Article 3. The expected result would be the production of more picturesque designs for buildings. Those architects who designed opposing buildings on a street in this manner, at lower heights than the maximum 20m allowed for the facades, would have even greater artistic licence available to them.
- *Articles 9-16* made further changes to the 1884 regulations about internal courtyards. They were to have a minimum surface area of 30m^2, and, depending on the dimension chosen, rules were set for the minimum space in front of windows of inhabited rooms that faced onto the courtyards. Furthermore, as the containing walls around courtyards rose, so the allowed internal facade heights and angles of set-back were calculated relative to that space. In response to those who suggested that calculating this new approach would be too complex for Parisian architects, Bonnier retorted that it would lead in his opinion to many new design solutions and hence a much more rational application of hygiene rules.
- *Article 17* ensured that the ground and first floors were at least 2.8m high and all other floors not less than 2.6m high. Bonnier triumphantly announced the end of what he felt were detested *entresols* or

[281] For more on early North American skyscrapers see: Jane Bonshek, 'The Skyscraper: A Catalyst of Change in the Chicago Construction Industries, 1882-1892', *Construction History* 4 (1988): 53–74; Thomas Leslie, 'Built like Bridges: Iron, Steel, and Rivets in the Nineteenth-Century Skyscraper', *Journal of the Society of Architectural Historians* 69, no. 2 (June 2010): 235–61.

mezzanines used to fill buildings with extra floors within the overall facade and roofing height limits.[282]

- *Articles 20 to 26* covered projections (*saillies*) from buildings outwards into the street. The overriding principle was that those buildings which were already set back from the street could benefit more from new allowances for these projections, hence there was an even greater incentive to build further back as per Articles 7 and 8. These *saillies* had been the subject of the unsatisfactory 1882 regulations and were mainly balconies and bay windows, for which new proportional limits were set: these covered the allowable extent of their protruding surfaces as a proportion of the overall surface area of a building's facade.

Bonnier summarised the regulations in a final item for the *L'Architecture* series that was published in March 1903. He emphasised that he and his colleagues in the City administration were public servants and so more than willing to assist commissioners, designers and constructors in interpreting and abiding by the revised rules.[283]

The impact of the 1902 revisions to Parisian street regulations

What impact did the new street regulations have on Parisian architecture during the *Belle Époque*? Bonnier's biographer, architectural historian Bernard Marrey, thought they were significant in that they provided new freedoms for aspiring young *Art Nouveau* architects, though this was quickly scotched after the First World War by International Modernism:

> In fact, this decree allowed the construction of some of our most beautiful 'Art Nouveau' buildings. Without touching the volumes defined by the decree of the Second Empire, [Bonnier] authorized a freer and more picturesque architectural expression, which the next generation would condemn, in the name of an unfailing purism.[284]

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[282] Bonnier was expressing here the broad views of his professional colleagues as he personally saw them, but it is assumed the comment was driven by Parisian urban hygiene requirements related to over-crowding.
[283] Bonnier, 'Les Nouveaux Règlements de Voirie a Paris', 1903, 116.
[284] Bernard Marrey, *Louis Bonnier, 1856-1946* (Mardaga, 1988), 60. « De fait, ce décret permit la construction de quelques-uns de nos plus beaux immeubles 'Art nouveau'. Sans toucher aux volumes définis par le décret du Second Empire, il autorisa une expression architecturale plus libre et plus pittoresque, dont la génération suivante condamnera, au nom d'un purisme sans faille. »

François Loyer took a broader perspective on the significance of this influence. While acknowledging that Parisian *Art Nouveau* design benefited from the increased freedoms of the new regulations, he also pointed to the structural and planning related advantages that arose for the city:

> The urban architecture of Paris, between 1900 and 1930, was the product of an elaborate reflection in the last years of the century, through the facade competitions of the city[285] as well as through regulatory projects … To be accurate, there are two contradictory practices that we will evoke in turn: one of a kind of parched Haussmannism, drawing in a radical way the lessons of the Second Empire, and the other of an exuberant eclecticism whose *raison d'être* is, above all, to oppose the previous one. We will find, with even more brilliance, this duality in *Art Nouveau*. [286]

In addition to the transformation of proportionality in the traditional post-Haussmann street, the now fully-regulated projection of bay windows saw a welcome break of alignment for each building facade. New, more hygienic open courtyard arrangements also destroyed the monotony of previously uniform streets and saw the introduction of a novel type of urban space, *l'avenue à redents* or more correctly *redans*; this design for a tooth-like street profile was applied for the first time by French architect Eugène Hénard during the completion of the Boulevard Raspail in Paris. Loyer saw the new development of these *redans* as permitting the installation of planting areas in front of buildings that were slightly set back from the street and so added a little greenery to the facades.[287] Sutcliffe by contrast largely dismissed the long-term impact of the 1902 revisions, citing a counter-movement for heritage preservation that emerged soon after they were imposed on the capital, thus dampening the fervour of those *Art Nouveau* proponents like Bonnier and some of his more radical peers. Plans were in fact soon put in place to reform the reforms, so as to rectify their perceived negative effects on the historic Parisian cityscape, and even Bonnier himself was involved in the new process – this last may have partly explained why in the end nothing significant ever happened, also due to the forced

[285] The annual Parisian facade competitions had been established at the end of the nineteenth century to encourage aesthetic creativity in design, as a package together with the regulatory revisions. The *immeuble* at 9 rue Claude Chahu completed in 1903 was a competition winner and features in the case study of Parisian immeubles with decorative ceramic facade cladding in Chapter 5. For extensive commentary on these annual competitions see: Monique Eleb and Anne Debarre-Blanchard, 'Architectures de La Vie Privée. La Belle Époque de l'habitation, 1880-1914. Tome 2' (Ministère de l'équipement et du logement / Bureau de la recherche architecturale (BRA); Ministère de la recherche et de la technologie; Ecole d'architecture de Paris-Villemin., 1989), 317–50.
[286] Loyer, *Paris XIXe Siècle. L'Immeuble et La Rue*, 269, 376.
[287] Loyer, 413.

interruption of two major wars in the 1910s and 1940s – hence the next significant change to the Paris street regulations only occurred in the 1960s.[288]

While the *immeuble* at 1 rue Danton was designed and completed in 1900, so prior to the new decree, it is a case study at the end of this chapter as it has interesting pre-regulatory features that deserve more detailed consideration. The building is situated in a small triangular-shaped location at the end of the street opposite *la place Saint-André-des-Arts* in the *Quartier Latin* of central Paris. The architect Édouard Arnaud had to maximise internal space within the limits of city regulations on building heights and adjoining walls: he did this by reducing the thickness of the non-adjoining and internal walls as well as the floors, a key advantage of using a monolithic construction system – of course he was required to employ the *béton armé* system by the building commissioner François Hennebique. Arnaud also used four columns of cantilevered bay windows to break the monotony of the facade caused by the thinness of the external walls, as well as responding to Hennebique's insistence that his architect should not hide the reinforced concrete structure and facade behind any ceramic cladding; the latter would happen in subsequent Parisian buildings, such as those at 9 rue Claude-Chahu (1903) and 185 rue Belliard (1913), which are both described in the case study in Chapter 5 on Parisian *immeubles* with decorative ceramic facade cladding. Even in his exercise Arnaud was further restrained by the existing city regulations, which would not allow the two middle columns of bay windows to be a direct copy of the outer ones, producing in his mind a less harmonious overall effect, with which his contemporaries agreed – though it is not clear whether the revised regulations would have improved things, given their restrictions in Articles 20-26 on the relative share of the facade surface area allowed for projections into the street. Arnaud did manage to fill the roof vaulting with two floors of storage space (possibly not permitted so easily after 1902) and included a roof-terrace at the top of the building (which *was* encouraged by the new regulations); this was all set back from the normal alignment as a waiver to the existing requirements and in anticipation of the revised 1902 street-side *gabarit*.

How did the 1902 changes to the street regulations relate specifically to the historic example buildings in the case studies that were constructed in Paris after that date? Table 2.2 in the Appendices shows four of these whose architectural features may have been influenced to a lesser or greater extent by the new freedoms

[288] Sutcliffe, *Paris: An Architectural History.*, 125–26, 166.

introduced. Overall, looking at the four historic buildings included in the table, there is something to show in terms of direct influence of the revised street regulations. They all probably gained more internal space, like the *immeuble* at 1 rue Danton, from the technical advantage of thinner, load-bearing floors and thinner external walls, depending on their use of the reinforced concrete or cement systems. Three of them employed projections in the form of bay windows, but one had none at all – instead the HBM complex on rue de la Saïda in Paris (see the case study on HBMs in Chapter 3) used an open staircase system for specific social housing reasons. Arguably all of these components might have been included whether or not the regulations had been revised. The roof-terracing, large rear courtyard and spaced blocks were all probably encouraged by the general tone of the regulatory changes, which themselves reflected the new technical possibilities and creative desires. It is worth noting that the *immeuble* at 25b rue Benjamin Franklin by the Perret brothers, examined in more detail in Chapter 6, was a unique urban building completed in 1904 that used an adaption of the Coignet system and *does* seem to have tried to fit itself imaginatively within the parameters set by the revised Parisian street regulations, though this was not a design priority.

In terms of the wider impact of these new regulations outside the French capital, Bullock and Read maintained that during the *Belle Époque* municipal authorities were not powerful enough to control social housing by offering land or buildings to builders – and that Paris as the capital of a very centralised nation set the trends that the regions might only subsequently follow if so inclined. However, they considered that the introduction of new, less restrictive regulations for Paris from 1902 onwards did at least start to change the balance from individual politicians to a more socially representative group. This was reinforced after the First World War in Paris, when rent controls remained in place to protect working class tenants; however, together with the post-war economic uncertainty, these failed to encourage private investment in housing, a continuation of the state of affairs pre-war. Hence the growing need for more direct state intervention in construction funding and planning, that eventually took off on a much grander scale in the interwar years and beyond both in Paris and further afield.[289]

[289] Bullock and Read, *The Movement for Housing Reform in Germany and France 1840-1914*, 284–85.

Case study: The immeuble at 1 rue Danton, Paris

The French architect Édouard Arnaud built an *immeuble* containing the main Hennebique design offices with apartments at 1 rue Danton, Paris between 1899 and 1900, using the specialist contractor for the *béton armé* system, Louis Roquerbe (see Figures 2.9 (a) and (b) and 2.10 (a) and (b)).

This had been an opportunity for François Hennebique to promote his reinforced concrete system to international visitors to the 1900 Paris *Exposition Universelle*. The first published report on the building appeared in the August 1900 edition of *Le Béton Armé*, which told of a public visit to the site by delegates to Hennebique's annual conference in Paris, as well as by other well-known international architects and engineers who had no doubt been attracted by the larger Parisian event:

> Let us simply mention now the admiration of the visitors for the whole construction, whose plans were designed by the architect Arnaud, who made it an innovative work by finding in the use of reinforced concrete a very special architectural character, as well as for the exterior walls of a small section, the arched floors of the basements, the thin partitions, the stairs and their sections, the well-lit courtyards, etc.[290]

A less euphoric and therefore more objective assessment of the building came in April of the following year through a series of articles in *La Construction Moderne*.[291] Here we first find out more details about the purpose of the building, with its eleven levels separated into office space for the Hennebique business's operations, François Hennebique's private accommodation in Paris and two separate apartment-floors for other occupants. The author points out the smallish, triangular-shaped plot which required the architect to maximise use of space. In fact the total surface area gained by employing the *béton armé* system, which permitted thinner walls to be used, was in the order of ten square meters per floor and was extended further by the use of the under-roof spaces to hold business archives, lit by daylight from an internal courtyard, and roof-terracing at the very top.

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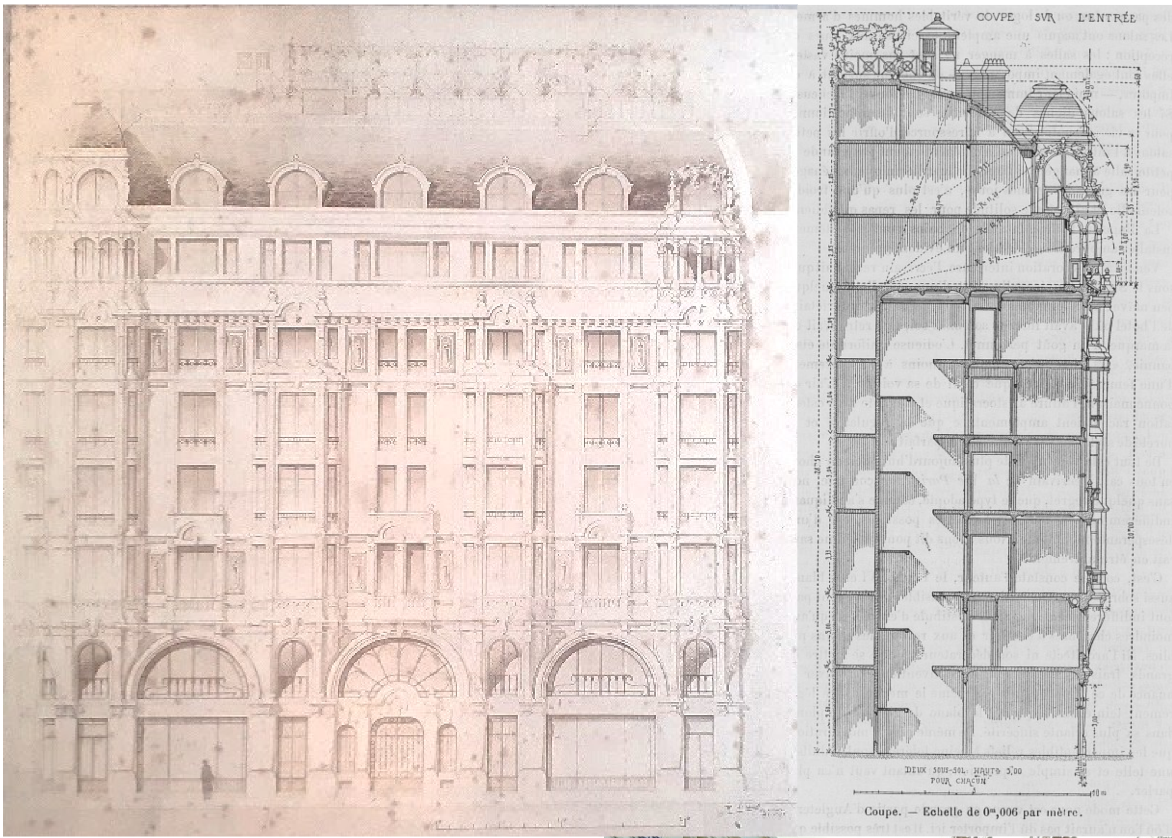
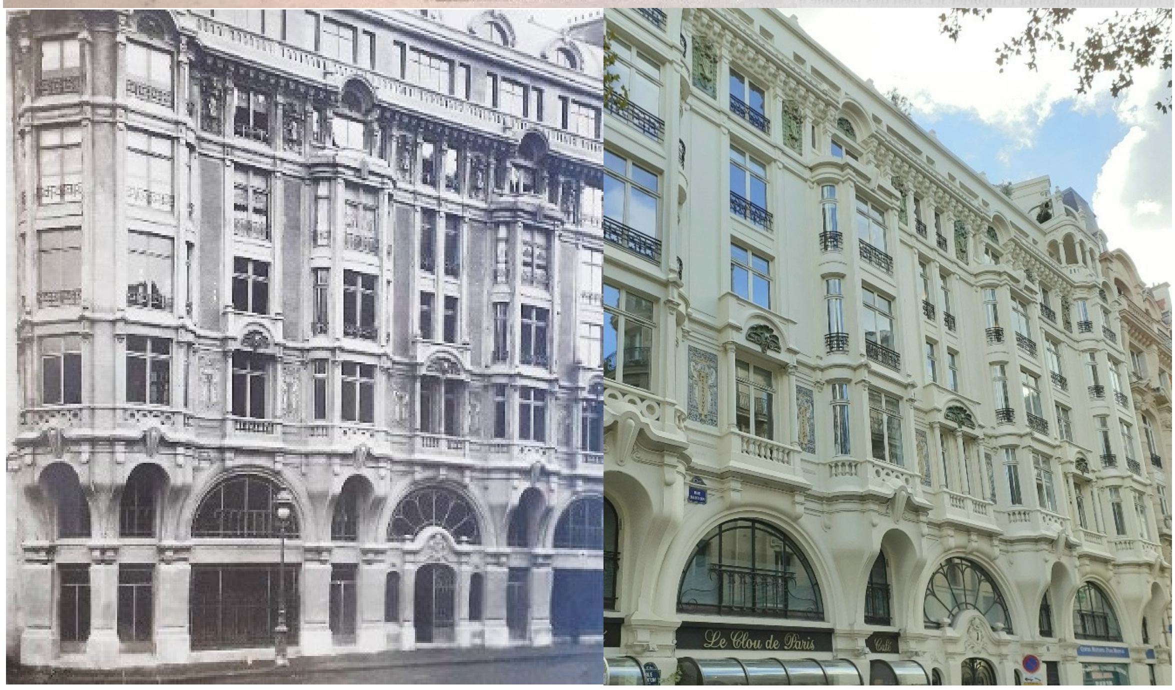
[290] Georges Flament, 'Quatrième Congrès Du Béton Armé. Séance Du Mardi Soir, 21 Août 1900', *Le Béton Armé* 3, no. 29 (October 1900): 13. « Disons simplement maintenant l'admiration des visiteurs pour l'ensemble de la construction, dont les plans ont été conçus par M. l'architecte Arnaud, qui a fait œuvre de novateur en trouvant dans l'emploi du béton armé un caractère architectonique très spécial, ainsi que pour les murs extérieurs de faible section, les planchers en arc des sous-sols, les réfends minces, les escaliers et leurs pans, les courettes si bien éclairées, etc. »

[291] 'Maison Rue Danton à Paris', *La Construction Moderne* 6, no. 28, 29, 31, 33 (1901).





Figures 2.9 (a) and (b): An original design elevation (top left) and section (top right) of the immeuble at 1 rue Danton, Paris (Arnaud, 1900), illustrating the large number of floors of which the top three form a mansard roof with terrace above.

Figures 2.10 (a) and (b): The street view of the same building in 1900 (below left) and today (below right) showing the effect of the bay windows and other elements of the facade design.

(76 Ifa 1/1. CNAM/SIAF/Cité de l'architecture et du patrimoine/Archives d'architecture contemporaine, La Construction Moderne, Vol. 6, No. 28, 1901, p.328 & Nick von Behr)

The main design offices were situated on the fifth and sixth floors, including a recessed balcony along its whole length. The intersections of rooms and staircases that faced onto the internal courtyard were glazed from the ceiling down to the floor. The street facade of the building illustrated the architect's fears on how best to express its architecture through the use of concrete and cement cladding, rather than traditional materials. This was successfully achieved by using bay windows and other architectural elements to reflect the building's novel monolithic skeleton (Figures 2.10 (a) and (b)).

The building was next reported on by the architect-critic Pascal Forthuny, with a response by Édouard Arnaud, in the May 1901 edition of *Le Béton Armé*.[292] Forthuny pointed out that the building had attracted considerable critical commentary from both architects and engineers. He set the scene for the subsequent exchange with Arnaud, noting that the architect had interpreted the building facade in a manner conducive to its use of reinforced concrete and the Parisian setting, hence it was not a pure imitation of traditional masonry craft skills. He identified opponents of building design innovation, constituting a dangerously hostile group of first architects, who refused to know more about the novel materials-system, as well as contractors, who were concerned about managing the risks associated with its use in their projects:

> … in their same verdict, all the expressions of this new architecture were confused, that in which the most rigorous science verified the most resistant construction, and also in which disparate materials intervened only fancifully, used without method or reason.[293]

Forthuny explained briefly the structural use of the novel materials-system, insisting that he would focus on its architectural application to better understand whether the designer had successfully achieved something truly novel. He applauded Arnaud for meeting a difficult design brief through key structural requirements, in constructing a building on a difficult plot and within specific constraints set by the client as well as the city regulations, but at the same time producing an architectural composition of merit. He particularly praised the penetration of the exterior walls allowing more daylight into the interiors, as well as the fact, as he saw it, that the facade wall was both a resistant and a transparent barrier, breaking the monotony, pierced and enlarged by the bay windows:

[292] Pascal Forthuny and Édouard Arnaud, 'Le Ciment Armé Du Rue Danton à Paris', *Le Béton Armé* 3, no. 36 (May 1901): 1–5.

[293] Forthuny and Arnaud, 1. « … on confondait dans le même verdict toutes les expressions de cette architecture nouvelle, celle où la plus rigoureuse science vérifiait la plus résistante construction, et celle aussi où n'intervenaient que fantaisistement des matériaux disparates, employés sans méthode ni raison. »

> … all these facade transitions were logically reasoned, to obtain the play of light and shadows that a reinforced concrete facade, without decorative thickness, does not have in itself.[294]

Forthuny maintained that *ciment armé* and *béton armé* (used interchangeably) could not simply be used to imitate traditional materials to fit with surrounding Parisian buildings. He regretted that Arnaud had not been more confident in projecting his own original design ideas onto the facade:

> Casting can give remarkable results. But let us never mould simply anything, let us never fall back on eternal motifs catalogued in the collections of ancient decorative arts, let us instead take the opportunity to try once again to renew a solid connection between the last vestiges of an art which has a unity, a harmony like the Louis XVI style, and the blindly eclectic time in which we now live.[295]

Édouard Arnaud's response was respectful. He agreed that new building materials should promote new forms of architectural expression. However, *béton armé* had until then not been properly defined as a distinct materials-system, due in part to the increasing variety of generic systems available. He believed it could replace traditional construction systems in many of its structural aspects – for example, instead of the use of iron and timber in the lintels, floors and trusses, which observers would not be able to distinguish at a glance:

> … it is only by examining the details or parts, that one can recognise the reality. Concrete can also take the place of stone in the sills of windows, in cornices and this most logically, since we have gone so far as to build concrete blocks that are used as blocks of stone.[296]

Arnaud maintained that *béton armé* would always be clad rather than allowed to show its true appearance. Within this cladding process he pointed to his skilled Italian workers who produced artistic results with

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[294] Forthuny and Arnaud, 2. « … tous ces mouvements de façade étaient logiquement raisonnés, pour obtenir les jeux de lumière et d'ombres qu'une façade en béton armé, sans épaisseur décorative, ne comporte pas en elle-même. »

[295] Forthuny and Arnaud, 2–3. « Le moulage peut donner de remarquables résultats. Mais qu'on ne moule point n'importe quoi, qu'on ne se rejette point sur les éternels motifs catalogués aux recueils d'art décoratif ancien, qu'on profite de l'occasion pour essayer une fois de plus de renouer un lien solide entre le dernier vestige d'un art où se manifeste une unité, une harmonie, le Louis XVI, et le temps aveuglément éclectique où nous vivons. »

[296] Forthuny and Arnaud, 3. « … ce n'est que par l'examen des détails ou des parties que l'on peut se rendre compte de la réalité. Le béton peut aussi prendre la place de la pierre dans les appuis des fenêtres, dans les corniches et cela des plus logiquement, puisque l'on a été jusqu'à construire des blocs de béton que l 'on met en œuvre comme des blocs de pierre. »

moulded cement, but also to the use of tiles, ceramics and plasters. Arnaud, however, did not believe that the novel materials-system would develop its own distinct architectural style, as Forthuny had suggested:

> How much more difficult is the work of the architect, who also, as an artist, is subjected to criticism all the more dangerous, because everyone claims to know about it. He first has the same difficulty to overcome, with the difference that the means at his disposal are not always expressive.[297]

Arnaud then explained his particular approach to the facade of the *immeuble* at 1 rue Danton; part of this related to the restraints place on architects by Parisian municipal regulations referenced earlier, which would not allow the two middle columns of bay windows to be a direct copy of the outer ones, producing in Arnaud's mind a less harmonious effect. He agreed with Forthuny's appeal for more trial and error in the creation of moulded cement cladding for facades of buildings with reinforced concrete or cement skeletons.

Le Béton Armé returned to the *immeuble* at 1 rue Danton in the autumn of 1901.[298] The new piece focused more on the technical issues to do with the building's skeleton, covering all aspects from the foundations to the roof, accompanied by a range of technical illustrations (Figures 2.11 (a) and (b)). The writer included the following summary of the benefits of its structural efficiency as a key structural requirement:

> This created a skeleton of equal strength at all points, established using homogeneous materials with no solution of continuity and with dimensions such that the general cube of the materials used does not reach a third of that which would give an ordinary construction on a surface of equal size; while obtaining a superior solidity both because of the monolithic character of the structure and the indestructibility of the materials used.[299]

The mention of the building's 'monolithic character' is important since this had become a key selling point for the *béton armé* system, at least in industrial buildings, and indeed it started to apply increasingly to the

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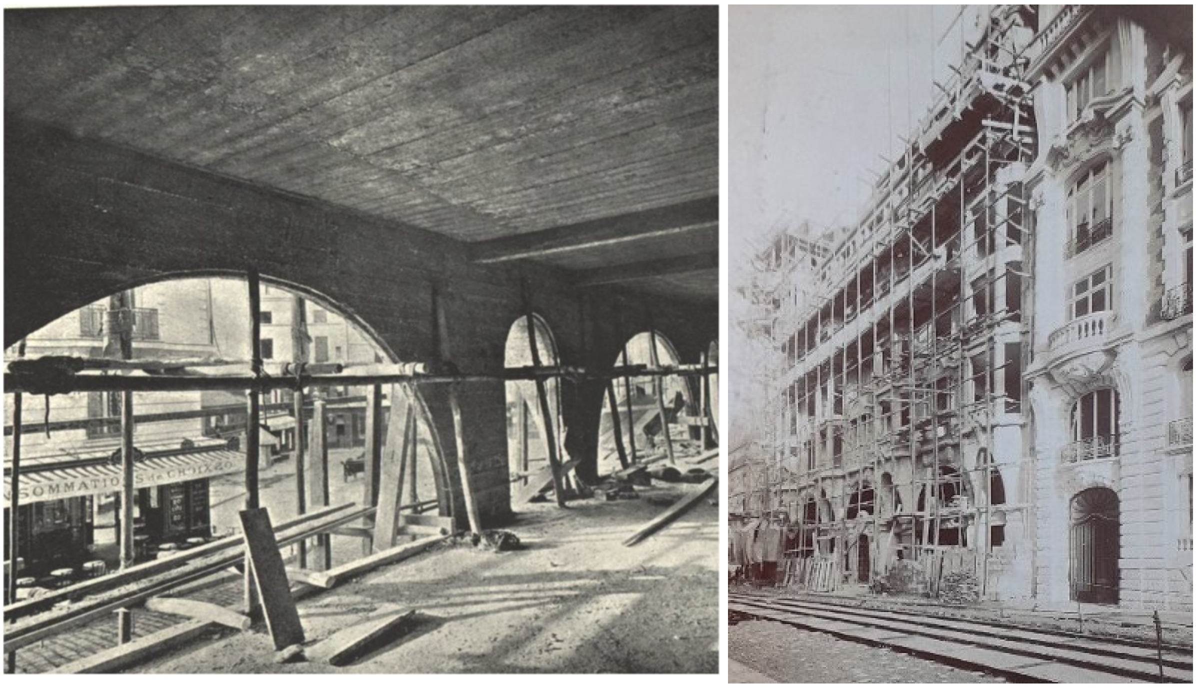
[297] Forthuny and Arnaud, 4. « Combien est plus difficile l'œuvre de l'architecte, qui pourtant, lui aussi, en sa qualité d'artiste, est soumis à la critique d'autant plus dangereuse, que tout le monde prétend s'y connaître. Il a d'abord la même difficulté à vaincre, avec cette différence que les moyens dont il peut disposer ne sont pas toujours expressifs. »

[298] 'Maison de Rapport Rue Danton No.1 à Paris', *Le Béton Armé* 4, no. 41 (October 1901): 57–63.

[299] 'Maison de Rapport Rue Danton No.1 à Paris', 62. « On a obtenu ainsi une ossature générale d'égale résistance en tous ses points, établie en matériaux homogènes ne présentant aucune solution de continuité et avec des dimensions telles que le cube général des matériaux employés n'atteint pas le 1/3 de celui que donnerait une construction ordinaire sur une surface d'égale grandeur, tout en obtenant une solidité certainement supérieure tant en raison du caractère monolithique de l'édifice que de l'indestructibilité des matières mises en œuvre. »

broader materials-system (see Chapter 2 on structural efficiency as a key structural requirement that includes monolithism).



Figures 2.11 (a) and (b): Contemporary photographs taken during the construction of the immeuble at 1 rue Danton, Paris (Arnaud, 1900), showing the use of the béton armé system for floors, ceilings and mezzanine windows (left) and the scaffolding system for the street facade (right). (Le Béton Armé Vol. 4, No. 41, 1901, plate III & 76 Ifa 1/1. CNAM/SIAF/Cité de l'architecture et du patrimoine/Archives d'architecture contemporaine)

The building was subsequently referenced in Christophe's 1902 technical guide, singling out the thinness of the facade walls of eighteen centimetres, contributing to the gain in overall floor area.[300] The *immeuble* was also included in a report of the same year on a site visit led by Arnaud himself for delegates to the Thirtieth National Congress of French Architects in Paris, which provided another useful summary of structure and facade:

> Minimum points of support, minimum thickness of the walls, minimum thickness of the floors – which allowed eight floors above the ground floor, while remaining within the legal limits – basement perfectly waterproof, although placed 3 meters below high water, such is the result obtained. As for the facade, as Mr. Arnaud himself says, the experience of the rue Danton shows that reinforced concrete can be asked to perform all the architect's design intentions.[301]

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[300] Christophe, *Le Béton Armé et Ses Applications*, 159.
[301] L. George, G. Olive, and G. Rozet, 'XXXe Congrès Des Architectes Français. Séances, Visites, Excursion. Compte Rendu Sommaire (Suite).', *L'Architecture* 15, no. 27 (1902): 223. « Minimum de points d'appui,

It is curious that Arnaud appears here to retreat from his more equivocal response to Forthuny about the architectural merits of the facade. A few years later, Louis-Charles Boileau wrote about the *immeuble* at 1 rue Danton as part of a general commentary on the architectural merits of employing reinforced concrete (for more on this see Chapter 5); Boileau, who had been a long-time supporter of Hennebique's *béton armé* system, asked rhetorically about its artistic worth, paraphrasing the inventor's reply:

> I offer you a combination of two materials, admirable since it makes it possible to preserve indefinitely, without any alterations. The frame of iron, a remarkable system because it can, by applying it judiciously, make works that are both extremely powerful and solid, economical on top of that. It is, I imagine, already very kind to you artists, to seek what can be derived from it, in addition to the benefits acquired in civil engineering for the creations of art![302]

Boileau credited Arnaud and his craftsmen for trying to demonstrate the aesthetic qualities of a reinforced concrete skeleton. Nonetheless, he criticised the facade for its ugly cement moulding, in his view contributing to little artistic engagement in the whole structure. Arnaud reflected back on his endeavours on the *immeuble* at 1 rue Danton sixteen years later. He gave a less than glowing endorsement of these aspects of the novel materials-system to future architects and civil engineers, justifying his original actions by maintaining that reinforced concrete was imposed on him by Hennebique as the only allowable approach for this building:

> ... let us preserve and use artistically the good and beautiful materials that we have at our disposal, and which does not exclude the use of reinforced concrete; but let that material play its true role in the

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minimum d'épaisseur des murs, minimum d'épaisseur des planchers,- ce qui a permis d'avoir huit étages au dessus du rez-de-chaussée, tout en restant dans le rayon légal, - sous-sol parfaitement étanche, bien que placé à 3 mètres en contre-bas des hautes eaux, tel est le résultat obtenu. Quant à la façade, comme le dit M. Arnaud lui-même, l'expérience de la rue Danton montre que l'on peut demander au béton armé de réaliser toutes les conceptions de l'architecte. »

[302] Louis-Charles Boileau, 'Le Ciment Armé et l'Art de l'Architecture', *L'Architecture* 18, no. 49 (December 1905): 455. « Je vous offre une combinaison de deux matières, admirable puisqu'elle permet de conserver indéfiniment, sans altérations aucunes. Le fer d'ossature, un système remarquable parce qu'on peut, en l'appliquant judicieusement, réaliser des ouvrages à la fois extrêmement puissants et solides, économiques par-dessus le marché. C'est, j'imagine, déjà bien gentil, à vous artistes, de chercher ce qu'on en peut tirer, en outre des bénéfices acquis au génie civil pour les créations le l'art! »

> structural skeleton, which is one of support, connection, protection, but not a role of filling and decoration.[303]

François Hennebique's headquarters in Paris have featured in the writings of a range of architectural historians over time. The authors referenced the key contemporaneous sources and used the building to illustrate wider points about *Belle Époque* architecture. Collins pointed to the *immeuble* at 1 rue Danton as illustrative context for Auguste Perret's own subsequent work with the novel materials-system – he suggested that it fitted into a early period typology of 'Conventional' buildings designed by Perret, in which reinforced concrete was used without deliberately emphasising the novelty of the materials-system or its difference when compared to brick or stone:

> Hennebique's office in the rue de Danton could be included under this heading, since although the architect, Arnaud, had carefully avoided clothing his reinforced frame in Renaissance or Gothic details, and had cantilevered the windows in quite an original way, his fear of shocking his contemporaries by radical innovations is as obvious to us as it was to them.[304]

Loyer saw the building as the prototype among only three examples, also including the HBM at 7 rue de Trétaigne by Sauvage and Sarazin (see the case study of HBMs in Chapter 3) and the *immeuble* at 25b rue Benjamin Franklin by the Perret Brothers (see Chapter 6), of rare and experimental Parisian buildings that used a reinforced concrete skeleton.[305] Subsequently, Jean-Pierre Épron's analysis of French eclectic architecture during the *Belle Époque* (see more on this in Chapter 5) also used the *immeuble* at 1 rue Danton to reinforce Louis-Charles Boileau's broader 1905 arguments.[306] By contrast, Legault returned to the counterposed articles by Forthuny and Arnaud that had been published in 1901. Rather than focusing, as the two original authors had done, on the merits (or not) of the decorative aspects of the street facade, Legault saw this more as the conception of the wall as a major component of the novel materials-system – for him, Arnaud had imitated

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[303] Édouard Arnaud, *Cours d'Architecture et de Constructions Civiles*, 1921, 37. « … conservons et utilisons avec art les bons et beaux matériaux que nous avons a notre disposition, et qui n'exclut pas le béton arme; mais laissons-lui jouer son vrai rôle dans l'ossature générale, qui est un rôle de soutien, de liaison, de protection, mais non rôle de remplissage et de décoration. »
[304] Collins, *Concrete. The Vision of a New Architecture*, 179.
[305] Loyer, *Paris XIXe Siècle. L'Immeuble et La Rue*, 448.
[306] Jean-Pierre Épron, *Comprendre L'Éclectisme* (Editions Norma, 1997), 137.

stone construction so as to give more solidity to the light exterior wall. The main architectural endeavour was therefore to find the appropriate representation for it:

> The facade wall had a uniform thickness of eighteen centimetres, including the cement coating and the thickness added by the decoration. Required to define an expression appropriate for reinforced concrete, the architect attempted to express the thickness of the wall. It is this choice which triggered a discussion on the architectural expression and decoration appropriate for reinforced concrete.[307]

Simonnet subsequently wrote briefly about the *immeuble* at 1 rue Danton in his much broader history of concrete, using it within the context of what he saw as a disorganised debate at the time between different views on the correct aesthetic approach to the material within urban architecture.[308] The most in-depth historical analysis of the *immeuble* at 1 rue Danton to date has been undertaken by Belli-Riz in a conference paper focused entirely on the building.[309] From a structural perspective, Belli-Riz concentrated on the technically-oriented reports in *La Construction Moderne* (May 1901) and *Le Béton Armé* (Oct 1901), singling out, for example, the gain in the number of floor levels by using thinner reinforced concrete slabs for floors, which was hence reduced from 30 to 12cm thickness. As for the famous street facade of the building, he contributed further to the extensive prior debate:

> On the facade of rue Danton we can still identify unusually sized openings and, if carefully observed, non-load-bearing fillings. Arnaud also managed to place ceramic decorations on some panels. He also deployed his art of relief in the moulding of cornices, entablatures, frames, bay supports. The identification of the material is then ambiguous, except for the total absence of visible joints.[310]

According to Belli-Riz, the architect’s treatment at sixth floor level stood out from the rest of the facade, because this was the location of the Hennebique business design offices; the bay windows were even wider at

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[307] Legault, ‘L’Appareil de L’Architecture Moderne: New Materials and Architectural Modernity in France, 1889-1934’, 82–83.
[308] Simonnet, *Le Béton. Histoire d’un Matériau, Economie, Technique, Architecture.*, 131.
[309] P. Belli-Riz, ‘Le Béton Armé à La Recherche d’un Style’, in *Édifice et Artifice. Histoires Constructives. Actes Du 1er Congrès Francophone d’histoire de La Construction*, ed. R. Carvais et al. (Picard, 2010), 641–50.
[310] Belli-Riz, 644–45. « Sur la façade de la rue Danton, on peut tout même noter que l'importance des ouvertures inhabituelle et, si on l' observe attentivement, parties en remplissage non porteur sont identifiables. Arnaud parvient aussi a placer des décors en grès sur certains panneaux. Il déploie par ailleurs son art du relief dans les moulures des corniches, des entablements, des chambranles, des appuis de baies. L'identification du matériau est alors ambiguë, hormis l'absence totale de joints visibles. »

this point and had no decoration, evoking a resemblance of an industrial building before other attempts to do so in a traditional urban setting, notably the *immeuble* at 25b rue Benjamin Franklin (see Chapter 6).[311]

The files on the *immeuble* at 1 rue de Danton at the *Archives de Paris* and the CAAC include design drawings, construction photographs and subsequent records of renovation works, many of which were cross-referenced by previous researchers. The building remains as impressive today as it must have appeared when first built, notwithstanding any architectural critique of the Arnaud's decorative approach to the street facade.

Chapter summary

Chapter 4 set out more societal context for *Belle Époque* construction using the novel materials-system, focusing on the role of specialist professionals involved with the technical design and construction process for buildings of the period. It could be argued that the commissioners of buildings, particularly if an organisation rather than a family business, were the principal channel for the collective views of all end users of the buildings; the effectiveness of such a channel still depends to this day on the range of interests represented and the method by which this representation is reflected in the final execution. Some of those building commissioners had strong operational drivers linked with their local textile economies in Northern France that served wider international markets. This is the region where François Hennebique first expanded his own business operations as the inventor of the novel *béton armé* system. For technical transmission to become fully established it required the key actors to have the necessary confidence and skills that would lead to the successful employment of the novel materials-system in finished buildings. Such a development saw 'sibling cooperation' between the building professionals involved, whether architect, engineer or contractor, or a combination of two or more; which brought with it implications for the nature of their professional status. It also required appropriate technical education in new specialist building systems and techniques, particularly for early career professionals.

The chapter continued with an examination of regulatory pressures on urban construction, focusing on Paris during the *Belle Époque*. Clearly any political pressures on construction were also connected to social factors, in the sense that quasi-democratic societies such as that of the French Third Republic, required a broader consensus about the urban environment mediated through elected representatives; whereas prior to 1870

[311] Belli-Riz, 645.

these matters had been the diktat of men such as *Préfet* Haussmann in Paris, in the service of his master Emperor Napoleon III. With the Third Republic in place after the disastrous 1870 Franco-Prussian War and the departure of Napoleon III, there was an opportunity for the city of Paris authorities to start afresh; however, due to a persistence of conservatism in the first few decades of the new democratic government, initial attempts to introduce more creative freedoms were tentative at best. After a concerted effort supported by key individuals, not least Louis Bonnier, a municipal architect-inspector who had strong connections to the architectural professional associations, the new regulations were successfully brought in as a slimmed-down version of existing legislation: the 1902 revisions to the Parisian street regulations were introduced in response to demands from French architects for more creative freedoms in building design, acknowledging that minimal urban hygiene requirements still had to be satisfied. The extent of influence of these specific changes to metropolitan regulations in Paris was limited in the long-term. They may have allowed a final flourish of the highly-decorative *Art Nouveau* architectural genre of Eclecticism within the French capital, but this only lasted until the outbreak of the First World War which brought much civilian building design and construction to an abrupt halt. By 1918, the impact of an intensive period of devastation in Northern France and Belgium had resulted in a drastically changed setting for interwar construction reflecting reconstruction priorities connected to shortages of men and materials. The chapter finished with a case study of the *immeuble* at 1 rue Danton in Paris (1900) which was completed just before the 1902 revised street regulations were finally published. It was a significant urban building that employed the *béton armé* system to help promote Hennebique's business interests, but in turn raised a whole series of issues about street decor for building skeletons using the novel materials-systems; this notwithstanding imminent regulatory changes.

Section 2 summary

Section 2 provided a societal context across two further chapters for *Belle Époque* construction using the novel materials-system. Chapter 3 considered social factors influencing the construction of urban housing and which led to the prioritisation of hygiene goals within building commissioner needs. These included a paternalistic concern for more affordable accommodation for the worse-off classes, that prevented the spread of disease within cities. The chapter ended with a case study of three historic examples of HBMs that illustrated the conversion of such commissioning needs into additional structural requirements for urban buildings. Chapter 4 examined the commissioners of the historic example buildings in the case studies, as well as the specialised role of the architects, engineers and contractors involved in the processes and outcomes of designing and building structures using the novel materials-system. The chapter drilled down into specific challenges faced by those contractors who had decided to specialise in novel reinforced concrete and cement systems (to be considered more fully later), as well as specialist technical education in the novel materials-system that became available to building designers. The chapter also covered the key municipal regulations in Paris that influenced building design during the *Belle Époque*. Initial regulatory pressures mediated by the controllers of Parisian street planning, not least Préfet Haussmann, derived from increasing nineteenth century demands for improved urban planning and hygiene described in Chapter 3. Contrasting pressures subsequently emerged as a form of artistic backlash, with a growing call amongst French architects for greater freedom of creative expression in their building designs. The chapter assessed the extent and long-term influence of the revised 1902 Parisian street regulations, which would not be changed until the 1960s, this despite a counter-movement emerging soon after their publication. A cased study of a key historic building completed just before the revised regulations is included at the end of the chapter.

A more complex schematic (Figure 2.12) expands on the earlier one in Section 1 by supplementing technical with societal context. The expanded schematic includes additional information blocks and details from Section 2, and now comprises:

1. Early industrial standards for reinforced concrete and cement systems, including their key components of industrial patents, structural specifications and technical guidance.
2. Key structural requirements converted from building commissioner needs: fire resistance, structural efficiency, daylight admission and street decor.

3. Social housing, with structural requirements derived from social attributes such as improved cleanliness and greater affordability of urban accommodation.
4. Professionalism, particularly a specialist confidence in the ability to use the novel materials-system with the right technical design skills that can be applied successfully within municipal regulations.

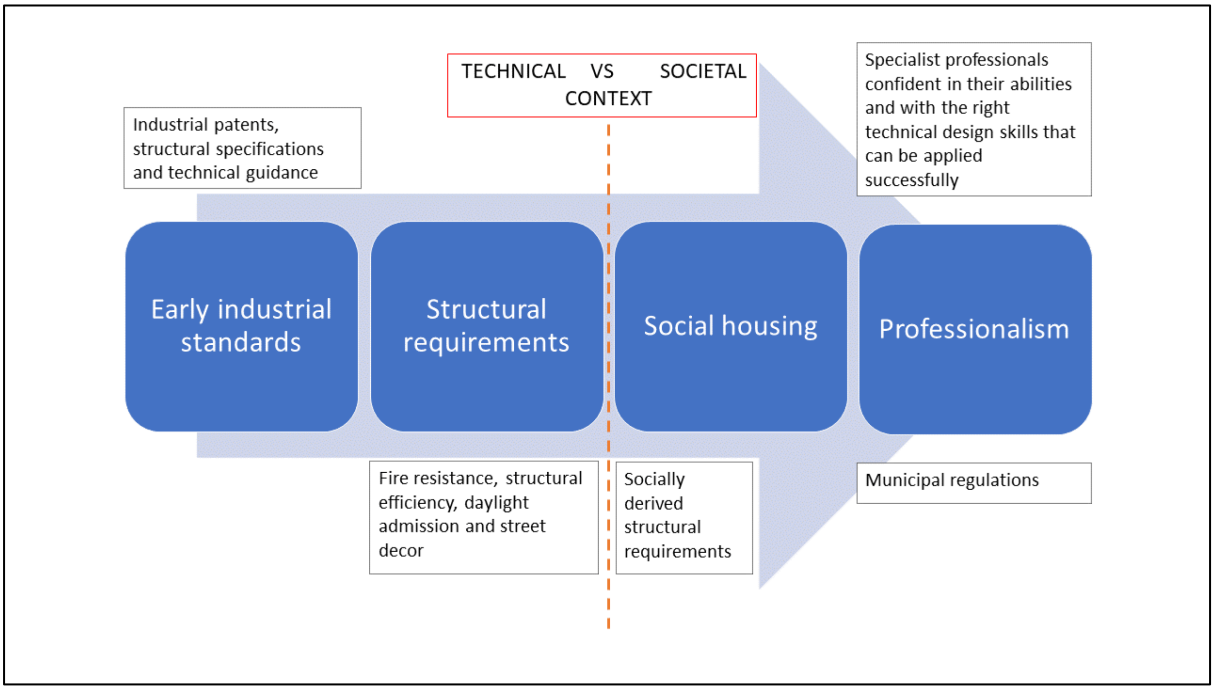

Figure 2.12: Schematic of the key information blocks and details in Sections 1 and 2.

The expanded schematic indicates a potential flow process (light blue arrow in the background) illustrating the possible causal relationships between all the information blocks and their details. The expanded schematic also answers the subsidiary research question asked at the start of Section 2, 'How did the employment of new reinforced concrete and cement systems reflect societal expectations and in what ways did these manifest themselves within building design and construction during the period?' by presenting two additional key information blocks of 'social housing' and 'professionalism' as well as their associated details. As will be seen in the final section, all these information blocks and details contribute towards the production of a historical mechanism that helps answer the core research question.

Section 3: The design of *Belle Époque* urban buildings using the novel materials-system

Section introduction

While the previous two sections examined the technical and societal contexts of *Belle Époque* construction using innovative reinforced concrete and cement systems, this final section covers the nature and outcomes of urban building design with the novel materials-system during the *Belle Époque*. It also introduces a historical mechanism, a key research outcome of the thesis. The section contains two case studies that, together with the context and analysis in both chapters, answer the subsidiary research question: 'Which factors shaped *Belle Époque* urban building design and how did they interact with key technical demands and societal expectations for the novel materials-system?'

The section begins in Chapter 5 by describing the first stage of a metallic building design revolution (1864-89), when iron and then steel were employed more extensively in building skeletons. Key features of eclectic architectural design and its more radical *Art Nouveau* genre are then considered, as is the second stage of the metallic building design revolution (1892-1914), involving the increasing use of novel reinforced concrete and cement systems such as *béton armé*. There is then a case study of two historic example buildings in Paris that employed reinforced concrete or cement skeletons with decorative ceramic facade cladding. The chapter concludes with a further case study of four historic commercial and administrative buildings in Brussels, Lille and its neighbour Roubaix that employed the novel materials-system in a new urban design approach.

Chapter 6 identifies two typologies (Urban Industrial and Urban Housing) derived from the case studies in previous chapters; specifically twelve historic examples of *Belle Époque* non-monumental, urban buildings in or near the three francophone cities of Paris, Lille and Brussels, all constructed using the novel materials-system. The chapter makes comparisons within and between the two typologies and indicates how they contribute to the production of a historical mechanism. This last integrates the information blocks and details on the technical and societal context in Sections 1 and 2, together with the building design context from this final section. The validity of the historical mechanism is confirmed using a well-researched Parisian reinforced concrete building from the *Belle Époque*. Chapter 6 concludes by reflecting on the professionalisation of specialist contractors and their role as intermediaries for these historic design and construction projects.

Chapter 5: A metallic building design revolution and *Belle Époque* Eclecticism

Chapter 5 introduces the twenty-five years between 1864-89 that constituted the first stage of a metallic building design revolution in France and Belgium, with the increasing use of iron and then steel in mainly monumental, urban building framing. The architectural characteristics of the *Belle Époque* are then considered, during which a flourishing of Eclecticism occurred in a post-Haussmannian phase after the start of the French Third Republic in 1870, culminating in the organically and geometrically elaborate *Art Nouveau* architectural genre. The chapter subsequently focuses on the maturation of novel reinforced concrete and cement systems from 1892 to 1914, as new non-monumental building design opportunities began to emerge for urban areas, all of this representing the second stage of a metallic building design revolution. There is a case study of two historic Parisian *immeubles* that both employed reinforced concrete and cement skeletons with decorative ceramic facade cladding The chapter ends with a further case study of four historic commercial and administrative buildings from this final period of the *Belle Époque* that all employed reinforced concrete or cement systems in a new urban design approach.

5a. The first stage of a metallic building design revolution

Britain was the world's first industrialising nation and created some unique and much-imitated structures: from Parliament's debating chamber and new textile mill sheds, all with internal cast iron supporting columns; vast iron and plate glass train sheds to serve the termini of the burgeoning new railway systems; and perhaps above all, the immense iron and plate glass international exhibition hall, 'The Crystal Palace' of 1851.[312] However, and with particular reference to the focus of this thesis on three francophone cities, there is considerable research evidence available on the use of iron in particularly French buildings during the eighteenth and nineteenth centuries; France became a world leader in the novel use of iron columns in largely monumental urban architecture through key architects, engineers and thinkers such as Jean-Baptiste Rondelet, Henri Labrouste, Henri Baltard, Louis-Auguste Boileau, Armand Moisant and Gustave Eiffel.[313] The

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[312] Robert Thorne, 'The Rebuilding of the Crystal Palace 1851-54: Permanent and Better?', *Construction History* 33, no. 2 (2018): 43–62.

[313] Siegfried Giedion, *Building in France. Building in Iron. Building in Ferro-Concrete.* (Getty Center for the History of Art and the Humanities, 1995); Steiner, *French Iron Architecture. Studies in the Fine Arts: Architecture, No.3.*; Bertrand Lemoine, *L'Architecture Du Fer. France: XIXe Siècle* (Champ Vallon, 1986); Laurent Koetz, 'Nineteenth Century Invention under Scrutiny. Louis-Auguste Boileau's Frame Construction Systems of around 1850.', in *Nuts & Bolts of Construction History. Proceedings of the Fourth International Congress on*

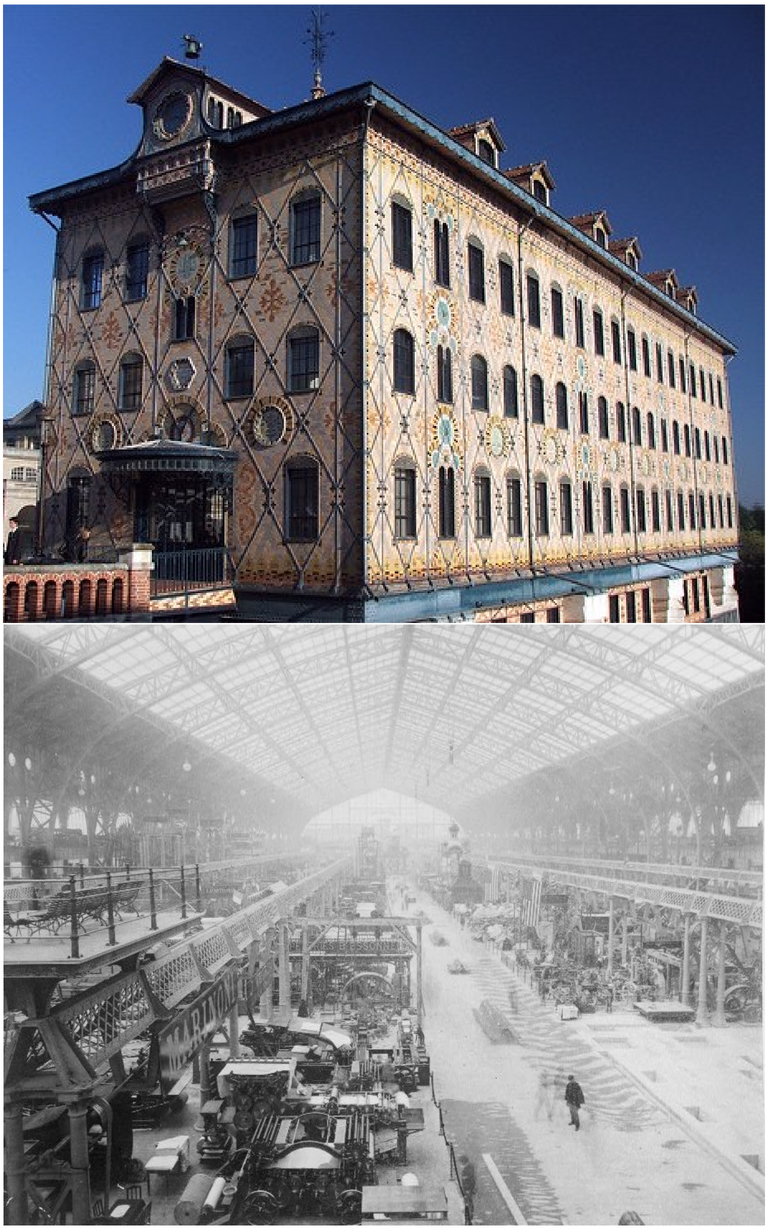
nineteenth century saw the increased use of point-bearing, metallic building framing, lessening the need (subject to municipal regulations and other local requirements) for load-bearing brick or masonry walls. As we have already seen in the previous sections, for reinforced concrete and cement systems this offered new options.

Building design in France experienced an extended revolution related to the new metallic-based construction technologies and included a number of key events, which took place within a converging process of growing aesthetic acceptance towards, and technical competence in, the use of iron and then steel in buildings. This development is shown in a first stage of a metallic building design revolution that took place over the twenty-five years from 1864 to 1889 and was exemplified by a selection of monumental structures built in Paris (with one nearby):

- the still extant *Gare du Nord* designed by the engineer Ignatius Hittorf with its iron and glass train shed that combined successfully with the more architectural aspects of the structure (completed 1864);
- the still extant *Bibliothèque Nationale* with its internationally-celebrated iron pillars, roofing and storage floors completed by architect Henri Labrouste (1868);
- the French architect-engineer team of Jules Saulnier and Armand Moisant completed the still extant first fully iron-framed building, at the Menier Chocolate Factory in Noisiel-sur-Marne, near Paris (1872, Figure 3.1 (a)) – while purely industrial and not typically monumental like the other structures in this list, the building took on a life beyond its functional existence by virtue of its technical originality and the fact that the industrial complex had architectural features designed to promote the chocolate business to elite French and foreign visitors;
- the ten iron and glass market halls at *Les Halles*, Paris, designed by the architect Louis Baltard and finished over a construction period of a number of decades (finally completed in 1874 and demolished with much controversy in the 1970s);

Construction History (ICCH, 2012), 185–92; Christopher Curtis Mead, *Making Modern Paris. Victor Baltard's Central Markets and the Urban Practice of Architecture* (Pennsylvania State University, 2012); Traisnel, 'Le Métal et Le Verre Dans l'architecture En France. Du Mur à La Façade Legère.'

- the still extant iron-framed and glass-roofed *Bon Marché* department store in Paris expanded by father and son architects Louis-Auguste and Louis-Charles Boileau, with engineering input from Armand Moisant and Gustave Eiffel (1887); and
- the first stage of the metallic building design revolution culminated at the 1889 *Exposition Universelle* in Paris and the triumphal expression of Eiffel's 300m iron tower (still with us), as well as the huge steel and glass exhibition hall that was the *Galerie des Machines* (sadly demolished, Figure 3.1 (b)) – these vast metallic structures were a step too far for many in the architectural profession at the time.



Figures 3.1 (a) and (b): The iron-framed cocoa refining mill, Menier Chocolate Factory, Noisiel-sur-Marne (Saulnier, 1872) (above - Photo: Myrabella / Wikimedia Commons) and the vast steel and glass Galerie des Machines (Dutert, 1889) at the 1889 Paris Exposition Universelle (below - Miscellaneous Items in High Demand, PPOC, Library of Congress, Public domain, via Wikimedia Commons).

The *Bibliothèque Nationale* by Labrouste (Figure 3.2) was the further development of a novel technical design and construction process the French architect had previously started with the *Bibliothèque Saint-Geneviève* (completed in 1851), also in Paris – in both of his libraries, Labrouste set large proportioned metal frameworks within masonry buildings, and this would particularly influence the later use of the novel reinforced concrete materials-system to construct monolithic skeletons:

> By individualizing each element of the construction and demonstrating that such a heterogeneous whole could create a strong sense of harmony, he thus paved the way for the great rationalist trend in European and American architecture at the end of the nineteenth century, which made a distinction between supporting structure and infill, expressively playing with materials and colour.[314]

Figure 3.2: Modern day photograph of Henri Labrouste's reading room at the Bibliothèque Nationale, Paris (1868), with its iron pillars and delicate iron vaulting. (Adelphilos, CC BY-SA 4.0 via Wikimedia Commons)

The *Galerie des Machines* was completed in time for the 1889 *Exposition Universelle* in Paris. Stamper covered in detail the construction of the *Galerie des Machines*, with its 115 metre span breaking the record previously set by the St Pancras Station trainshed in London completed some twenty years before.[315] The contractors

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[314] Corinne Belier, Barry Bergdoll, and Marc Le Coeur, 'Introduction', in *Henri Labrouste. Structure Brought to Light.*, ed. Ron Broadhurst (Museum of Modern Art, 2012), 20–23, 21-22.
[315] John W. Stamper, 'The Galerie Des Machines of the World's Fair, Paris', *Source: Technology and Culture* 30, no. 2 (1989): 339.

were the *Compagnie des Fives-Lille* and the *Société des Anciens Établissements Cail*, who were the leading competitors for iron and steel construction in France, but in this case needed to cooperate on the project to ensure its timely completion for the opening of the exhibition.[316] The same logic might have been be applied to the iron Eiffel Tower, but in effect that structure was designed and built by a tried and tested team led by Gustave Eiffel and his able engineer Maurice Koechlin with additional architectural input. The other key difference was, somewhat 'ironically', that the iron Eiffel Tower outlived the steel *Galerie des Machines*, which was demolished at the start of the twentieth century.[317]

The first stage of the metallic building design revolution was intellectually nourished by the writings of Viollet-le-Duc. His second series of lectures published in 1872 promoted, admittedly only in a footnote on page 327 of his Lecture XVIII, the technical triumph of the new Menier Chocolate Factory cocoa milling building of that year; but he also expounded on new, more visible structural approaches that integrated iron with traditional building materials such as masonry and timber in urban settings, and included an example *immeuble* that employed an iron skeleton.[318] As already described, the first stage of this metallic building design revolution involved cast and wrought iron as the key construction materials, emerging during the Enlightenment and becoming consolidated in the nineteenth century. This was an environment conducive to the full emergence of a rationalist building design approach, as Viollet-le-Duc's historicist response to the then dominant version of *Beaux Arts* neoclassicism acquired momentum with a new generation of architects. Legault, however, rightly emphasised both the tension within Viollet-le-Duc's particular approach to rationalism, even though it was supported by many *Belle Époque* architects, as well as the broader issue of the visibility of iron in a 'typical' urban setting:

> Architectural truth – both ethic and aesthetic – was to waver between the legibility of structures and the visibility of materials; between the real and the apparent … The use of iron in architecture prompted the Rationalists to relate the logic of the structure to the exposure of the material, drawing

[316] Stamper, 345 fn51.
[317] Gustave Eiffel, 'Travaux Scientifiques Exécutés à La Tour de 300 Mètres, de 1889 à 1900', in *La Tour de Trois Cents Mètres* (L. Maretheux, 1900).
[318] Eugène-Emmanuel Viollet-le-Duc, *Lectures on Architecture. Volume 2*, Translation (Sampson Low, Marston, Searle and Rivington, 1881), 41–44, 65–93, 316–39.

> the equation between reason and the visible. At the height of the 1889 Exhibition, the question of modern materials in French architecture was primarily an issue of external visibility.[319]

Legault thus noted that, in spite of their differing perspectives, most building actors of the period agreed that architectural forms could not simply emerge from a novel engineering structure – therefore the search for new aesthetic expression would continue to be the role of the architect.

Straub had previously included many references to the new rationalist approaches – his work in civil engineering history pre-dated British architectural historians such as Middleton and Collins who explored the re-emergence of a Romano-Gothic architectural tradition in France.[320] As the nineteenth century progressed into the twentieth century, and the economics became more favourable, iron in building framing was gradually replaced by stronger but softer steel, which was also employed for the metallic bars inside reinforced concrete or cement systems. Steel had a greater resistance to tensile forces per equivalent unit of weight when compared to other metallic and traditional building materials; it presented potential cost-benefit opportunities to French and Belgian constructors and could be used with more reassurance than cast iron, wrought iron or timber over longer spans in larger and taller buildings.[321] However, even the great engineer Gustave Eiffel did not trust steel as a 'softer' form of iron until it had fully proven its worth and hence his ground-breaking tower of 1889 used cast iron trusswork.[322] By contrast, the magnificent arched vault of the *Galerie des Machines* did use steel in the same year as the Eiffel Tower was completed (see Chapter 4), and the same decade had already seen the start of construction on Britain's Forth Bridge (completed in 1890) and Tower Bridge (completed in 1893), both impressive structures using vast amounts of Scottish steel.

5b. Eclecticism as a major *Belle Époque* architectural category

The flourishing of French (and Belgian) historically referenced architecture in the nineteenth century that was such a distinctive feature of the *Belle Époque* is typically given the all-encompassing label of 'Eclecticism'. Jean-

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[319] Legault, 'L'Appareil de L'Architecture Moderne: New Materials and Architectural Modernity in France, 1889-1934', 11 & 24.
[320] Straub, *A History of Civil Engineering: An Outline from Ancient to Modern Times*; Middleton, 'The Abbé de Cordemoy and the Graeco-Gothic Ideal: A Prelude to Romantic Classicism'; Middleton, 'The Abbe de Cordemoy and the Graeco-Gothic Ideal. Part II.'; Collins, *Changing Ideals in Modern Architecture 1750-1950*.
[321] For a helpful explanation of the properties of early steel see: Thomas C. Jester, *Twentieth-Century Building Materials. History and Conservation.*, 2nd ed. (Getty Conservation Institute, 2014).
[322] Eiffel, 'Travaux Scientifiques Exécutés à La Tour de 300 Mètres, de 1889 à 1900', 23.

Pierre Épron, in his thorough consideration of eclectic architecture in nineteenth-century France, maintained that it was not simply copying past styles, rather about architects taking account of growing technical and societal concerns in a modern approach:

> Eclecticism is pragmatic, tangible, effective and modern. It characterizes the approach of nineteenth-century architects who, from the July Monarchy to the end of the century and practically until the eve of the 1914 war, pursued a vast debate on technology, history and society ... Its object is not to place the modern building, through a parody, into an ideological construction from history, but on the contrary to situate it in the circumstances of the moment.[323]

The aspects of this architectural approach that responded to industrialisation could be troublesome for the many nineteenth-century proponents of Eclecticism. For example, the architects' association for the North of France reacted adversely in 1898 to a published critique of their contribution to regional architecture, particularly in the heavily industrialised area in and around Lille. This critique had been included in a report commissioned by the French *Ministre de l'Instruction publique et des Beaux-Arts* and so had elicited a firm public response on behalf of the local architectural profession – they complained that their industrial cities, perhaps more than in other regions, had produced functional buildings with little regard to aesthetics, and which, most of the time, were not even designed by local architects:

> These have been built hastily, especially from thirty years ago onwards, for the exclusive purpose of economy and speculation, and can in no way characterize the architectural value of a country. More than all, architects deplore and react with their personal efforts against this lack of taste.[324]

The French word *éclectisme* and the English word 'eclecticism' both stem from the Greek word '*eklektikos*' which implies selecting from a range of the best choices. Forty did not single out the term in his thought-provoking study of the language of modern architecture; unsurprisingly, because when International

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[323] Epron, *Comprendre L'Éclectisme*, 11-12. « L'éclectisme est pragmatique, concret, efficace, moderne. Il caractérise cette démarche des architectes du XIXe siècle qui, depuis la monarchie de Juillet jusqu'à la fine du siècle et pratiquement jusqu'à la veille de la guerre de 1914, poursuivent un vaste débat sur la technique, l'histoire et la société … Son objet n'est pas d'inscrire l'édifice modern, par le moyen du pastiche, dans une construction idéologique de l'histoire, mais au contraire de le situer dans la conjoncture du moment. »

[324] 'Industries d'art, Les Écoles et Les Musées d'art Dans Les Départements', *L'architecture et La Construction Dans Le Nord* 8, no. 2 (February 1898): 15. « Construites hâtivement, depuis, et surtout il y a trente ans, dans un but exclusif d'économie et de spéculation, elles ne sauraient en aucune façon caractériser la valeur architecturale d'un pays. Plus que tous, les architectes déplorent et réagissent par leurs efforts personnels contre ce manque de goût. »

Modernism eventually became the dominant architectural movement in the interwar years, it placed Eclecticism in the same pejorative or redundant architectural categories as Historicism or Mannerism. Hence, in his analysis of the term 'History', Forty quotes from the founding principles of the first *Congrès International d'Architecture Moderne* (CIAM) in 1928 which rejected all use of historical references. The Bauhaus curriculum developed by Walter Gropius in the 1920s, and applied by him subsequently at Harvard Graduate School of Design, had no significant place for architectural history; this then all became gradually instilled into the received wisdom of modernist architecture as the twentieth century progressed.[325]

More helpfully than Forty's necessarily limited approach, Épron describes how French architects borrowed the term *éclectisme* from their philosopher colleagues, who were facing similar intellectual challenges within a new and more open society, after the shock of the French Revolution had swept away centuries of autocratic direction; they could seize the opportunity and establish their own professional identity as the key individuals in French society responsible for coordinating urban construction and planning activity.[326] The debates on how to achieve this took place within the *ateliers* and associated competitions of the *École des Beaux Arts*, part of the process by which inter-generational groups of architects contested their favoured solutions to nineteenth-century problems of construction technique, architectural form, built structure and appearance.[327] Eclecticism connects back to Chapter 4, when considering the pre-existing sibling rivalry between architects and engineers as described by Saint and the broader concept of sibling rivalry *and* cooperation between new generations of structural specialists in both design *and* construction was introduced. That chapter had also examined the changing regulatory environment in Paris and its relationship with eclectic architecture, including a subsequent case study of the *immeuble* at 1 rue Danton, which had just been completed prior to the 1902 revisions to the Parisian street regulations and provoked criticism for the lack of creativity shown in its cement facade cladding to a *béton armé* monolithic skeleton. By contrast, Chapter 5 looks more broadly at the relationship between

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[325] Forty, 199. However, Forty went on to reconnect history with both Postmodern architecture and reinvented Modernist architects such as Daniel Libeskind, who in his view managed to integrate both genres, though again there is no mention of Eclecticism within this analysis. Forty, 205. On Gropius's Bauhaus/Harvard curriculum see: Jill E. Pearlman, *Inventing American Modernism: Joseph Hudnut, Walter Gropius, and the Bauhaus Legacy at Harvard* (Charlottesville: University of Virginia Press, 2007).
[326] Épron, *Comprendre L'Éclectisme*, 14–15.
[327] Épron, 18–19.

Belle Époque Eclecticism and the newly acquired technical knowledge and skills in the novel materials-system, received through the technical training of building designers and constructors.

One approach to the topic would be to work from generalised texts about the architecture of the three major francophone cities, covering the start of the French Third Republic in 1870 to the outbreak of the First World War in 1914. Another more targeted approach, which is more inclusive of the Belgian context, singles out the *Art Nouveau* architectural genre of Eclecticism as a highly creative and freer expression of building design that emerged in 1890s Brussels, led by Victor Horta and his peers, and rapidly expanded outwards to Paris and further afield. Here are two quotations about *Art Nouveau* that set the scene for further discussion about this more radical genre within Eclecticism – both reference the importance of (interior and exterior) decoration, as well as the transitory nature of the genre:

> Because it was a movement of essentially decorative origin and because its formulation aimed at originality made it the opposite of a unitary art – it was initially protesting – *Art Nouveau* totally exploded in the first years of the century. But, in the Parisian context, a whole milieu of architects from *Art Nouveau* had to extend its existence into Art deco, by creating a dampening formula – less personal but more coherent – of a style with discreet references, elegant lines, which perfectly integrated the architectural conquests of the end of the century.[328]

> Art nouveau was a short-lived fashion, its forms exhausted within a decade by their commercial overexposure and aesthetic reaction. Yet this vibrant movement forms a bridge to the twentieth century, when the legacy of nineteenth-century design theory mingles with the culture of the avant-garde desire to celebrate a break with tradition. By the late 1890s the domestic interior had emerged paradoxically enough as a prime focus of public debate on the relationship between environment and

[328] Loyer, *Paris XIXe Siècle. L'Immeuble et La Rue*, 436. « Parce qu'il était un mouvement d'origine essentiellement décorative et parce que sa formulation visant à l'originalité en faisait le contraire d'un art unitaire - il était d'abord contestataire - l'Art nouveau a totalement éclaté dès les premières années du siècle. Mais, dans le contexte parisien, tout un milieu d'architectes venus de l'Art nouveau devait en prolonger l'existence jusque dans l' Art déco, en créant une formule assagie - moins personnelle mais plus cohérente - d'un style aux références discrètes, aux lignes élégantes, qui intègre parfaitement les conquêtes architecturales de la fin du siècle. »

> modern consciousness, and it was here that art nouveau was to make its greatest challenges to convention.[329]

Could an *Art Nouveau* architectural genre have expressed itself sufficiently within the design parameters of at least some of the historic example buildings in the case studies in this thesis? And if the answer to the question is in the affirmative, then can one estimate its significance in terms of the bigger picture of *Belle Époque* Eclecticism? While these are difficult questions to answer conclusively, some broader observations can be made. A null hypothesis might be that one would not expect contemporaneous building designers to be able to fully express their creative design freedoms using 'dampening' reinforced concrete and cement systems for the structural aspects of their buildings; such a hypothesis might well conclude that the *Art Nouveau* architectural genre had aesthetic values linked much more to the wider decorative arts (as in Loyer's and Bergdoll's quotes), and much less to the structural aspects of building design. Troy picked up Loyer's commentary about the later significance of interwar Art deco and International Modernist architecture as 'industrialising' and 'commercialising' influences on *Art Nouveau* – this is also considered in Chapter 6 when applying the historical mechanism to the *immeuble* at 25b rue Benjamin Franklin by the Perret brothers:

> … the most characteristic examples are to be found in the department stores, where the stylized modernism of Art Deco was actively promoted and extensively exploited for its considerable commercial potential … What linked Le Corbusier to his contemporaries … was his conviction that the aesthetic criteria of modern design were to be located in a process of production. Notions of style and aesthetics were in his view tied to mechanical production which, he argued, were at once different from, yet systematically equivalent to, the craft procedures operative in the past.[330]

Art Nouveau architecture *had* become associated with a highly creative use of ironwork, often with accompanying coloured glazing, exemplified in the unique Brussels *hôtels* and other buildings of Horta and colleagues (see for example Figure 0.1); this presents one route to exemplifying the structural uses of iron at least in building design and construction. Artificial stonework and ceramic tiling as new approaches to facade cladding were used in conjunction with the novel materials-system. *Art Nouveau* works were distinguished by

[329] Barry Bergdoll, 'The Crisis of Historicism', in *European Architecture 1750-1880* (Oxford University Press, 2000), 269–80, 279.
[330] Nancy Troy, *Modernism and the Decorative Arts in France: Art Nouveau to Le Corbusier.* (Yale University Press, 1991), 4-5.

their organic and geometric features, present in many of the historic example buildings. These included the street fronts of the *immeubles* at 9 rue Claude-Chahu (ceramic stoneware) and 185 rue Belliard (geometric pattern decorative ceramic tiling), both in Paris and featured in the subsequent case study. In Brussels, there was the highly decorative interior of the extension to *Banque Brunner* (see the case study at the end of this chapter on four buildings in a new urban design approach) and the facade of the HBM at 32 rue Marconi with its cement moulding in an Egyptian theme – his last building was considered by Basyn to be a more mature form of the *Art Nouveau* approach by Govaerts' (see the case study of HBMs in Chapter 3). Both ceramic cladding and polychrome bricks were used in the street facade of the wool-conditioning complex in Roubaix (see the case study at the end of this chapter) and the HBM complex at rue de la Saïda in Paris (see the case study of HBMs in Chapter 3).[331]

The research for potential historic example buildings initially included a number of remarkable urban buildings in Paris and Brussels that employed metal structurally and in an overtly visible way, both internally and externally. Many of them also employed imaginative organic or geometric approaches to ironwork, glazing and facade cladding that placed at least some of their features within the *Art Nouveau* architectural genre of Eclecticism. Four stand-out urban buildings, that were designed and constructed with solely metallic building framing, deserve consideration as part of the legacy of this first stage of the metallic building design revolution, one that continued into the second stage, focused as it was on the employment of novel reinforced concrete and cement systems: *La Maison du Peuple* in Brussels by Victor Horta (completed in 1899, since demolished); and, all in Paris, the *immeuble* at 124 rue Reamur attributed to Georges Chedanne (completed in 1904, renovated in 2009), the HBM *Cité L'Argentine* at 111 Avenue Victor Hugo by Henri Sauvage and Charles Sarazin (completed in 1907, recently renovated), and *La Samaritaine Magasin 2* department store by Frantz Jourdain (completed in 1910, recently renovated).[332] Loyer singled out the third of these four buildings as an archetype that had its parentage in the theoretical metallic examples of Viollet-le-Duc, particularly his design project for an *immeuble* with an iron skeleton in Lecture XVIII of his *Entretiens*.[333] While *La Maison du Peuple*

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[331] In contrast to these buildings, the facade of the *immeuble* at 1 rue Danton in Paris (see the case study of the building in Chapter 4) attracted architectural criticism for its unsuccessful attempt to express acceptable street decoration using a cement-moulded facade.

[332] There are other examples of non-monumental metallic building framing used in buildings in Paris and Brussels, not least the famous extant department stores such as *Le Printemps* and the *Galeries Lafayette* in Paris or the 'Old England' in Brussels.

[333] Loyer, *Le Siècle de L'Industrie*, 271; Viollet-le-Duc, *Lectures on Architecture. Volume 2*.

had, as far as we can tell from available historical records, a purely iron building framing with no evident use of steel, and the HBM *Cité L'Argentine* used a zinc facade, the *immeuble* at 124 rue Reamur and *La Samaritaine Magasin 2* department store both showed ample evidence of the use of steel in their building framing, which largely remains in place.[334] All four buildings had externally and internally visible metal in the form of columns and beams of iron or steel, sometimes shaped by a distinctive *Art Nouveau* approach into sinuous organic forms (colloquially known as 'whiplash') or more geometric derivations.

Of the four buildings, *La Samaritaine Magasin 2* has received the most scholarly and conservation focus due in part to a major renovation completed in 2021, so it would seem appropriate to use it as a template against which others might be compared (Figure 3.3 (a) and (b)).

Figures 3.3 (a) and (b): The street facade (left) and interior of the main gallery (right) at La Samaritaine, Magasin 2, Paris (Jourdain, 1910), today, showing the architect's expressive use of iron, steel and glass. (both Nick von Behr)

[334] Paolo Portoghesi and Franco Borsi, 'Victor Horta Maison Du Peuple 1896', *Architectural Design* 50, no. 1/2 (1980): 36–41; Megan De Prins, 'La Maison Du Peuple by Victor Horta: A Structural Analysis for the Reconstitution' (Vrije Universiteit Brussel and Université Libre de Bruxelles, 2016); Hubert Lempereur and Jean-François Cabestan, *La Samaritaine, Paris* (Picard, 2015); Jean-Baptiste Minnaert and Jean-François Pousse, *La Samaritaine. Une Renaissance Architecturale.* (Archives d'architecture Moderne, 2022); Loyer, *Paris XIXe Siècle. L'Immeuble et La Rue*.

Frantz Jourdain was the creative force behind the brash *La Samaritaine Magasin 2* and much has been written about him as one of the spiritual fathers of the *Art Nouveau* architectural genre of Eclecticism, to some extent in the footsteps of Victor Horta and Hector Guimard, though less practised than either.[335] Jourdain was also the mentor to many of the younger generation of French architects who emerged in during *Belle Époque*, including the highly-talented Henri Sauvage, partner architect with Charles Sarazin of a historic example building at 7 rue de Trétaigne, for which Jourdain was indeed a building commissioner (see the case study of HBMs in Chapter 3); Sauvage would in the subsequent interwar years co-design with Jourdain a more historically-sensitive *Art Deco* extension to the original *La Samaritaine Magasin 2* department store, having already started to experiment before the Great War with this more restrained version of the *Art Nouveau* architectural genre of Eclecticism.[336] Clausen had much to say about the original building in her detailed analysis of the 1980s. She which saw it as a radically modern building, indeed one of the first permanent buildings in Paris to use structural steel (as opposed to iron) in a fully visible manner together with its extensive glazing:

> If the simplified, sober forms of Auguste Perret and Tony Garnier reveal new forces that were to determine the direction of architecture in the 20th century, forces gathering strength under the surface of Parisian life at the time, Jourdain's Samaritaine reflects that surface: the unbridled fantasy, frenetic gaiety, and pageantry of the *Belle Époque*.[337]

Jourdain had strongly supported the use of reinforced concrete in Sauvage's rue de Trétaigne HBM project, but he did not appear to have the same enthusiasm for the novel materials-system in the project for the *La Samaritaine Magasin 2* department store. Clausen suggested that this was due partly to his concerns about

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[335] Legault sees Jourdain as a key French proponent of what he terms 'architectural realism', a theoretical position between rationalism and classicism that "celebrated the technological aesthetic of the engineer and praised the transparent, lightweight, linear architecture of the new glass and iron structures." Réjean Legault, 'Between the Visible and the Legible. Iron and Reinforced Concrete in Fin-de-Siècle France', in *The Companions to the History of Architecture, Nineteenth-Century Architecture Part II. Debates on Structure, Materials, and Tectonic Expression*, ed. Martin Bressani and Christina Contandriopoulous, vol. 2 (John Wiley & Sons, Inc., 2017), 241–67, 260 fn17.

[336] Lempereur and Cabestan, *La Samaritaine, Paris*, 156–75.'Another progressive group to which Jourdain belonged was the *Société du Nouveau Paris*, formed in 1902 and devoted to the modernization of Paris. It urged architects to broaden their concerns beyond the design of fine monumental buildings and to consider more mundane but pressing urban issues such as the city's circulation systems, mass transportation facilities, and low-cost housing.' Meredith L. Clausen, *Frantz Jourdain and the Samaritaine: Art Nouveau Theory and Criticism* (Brill, 1987), 2.

[337] Clausen, 292.

the structural reliability of the new systems, as well as a keenness to benefit from the improved efficiency of on-site construction by using steel and iron components that were fabricated off site. However, in the end, Clausen concluded that the driving motive was because Jourdain was committed to “a revolutionary building that looked revolutionary. Reinforced concrete was solid, resembling the traditional look of stone; iron on the other hand embodied a wholly new modern, lightweight and transparent aesthetic.”[338] By the time *La Samaritaine Magasin 2* department store was fully completed in 1910, it had to some extent become anachronistic as the last significant overtly-metallic building of *Belle Époque* Paris. It was designed and constructed to have a striking, almost clashing, monumental presence within a historic part of the city centre, as the *Centre Pompidou* would do nearby many decades later – and this was what eventually doomed its famous, lit-up towers, hated by the city authorities, and which were removed when the building was eventually extended southwards to the Seine in the 1930s.[339]

It is possible to conjecture that by the time a disastrous continental war broke out in 1914, it should have been obvious that either the *Art Nouveau* architectural genre of Eclecticism, or reinforced concrete and cement systems, or both combined together structurally and aesthetically, would have triumphed in non-monumental, urban building design in France and Belgium. But this was not yet so.

5c. A new stage for a novel *Belle Époque* materials-system

The year 1892 marks the start of the second stage of a metallic building design revolution that impacted on *Belle Époque* urban buildings in and near the three cities covered by this doctoral research. In effect, as previously described, reinforced concrete and cement systems had first emerged earlier than that date in France and then Belgium. But it was François Hennebique’s lodging of four key Belgian and French patents in the period 1892 to 1893 that were sufficiently distinctive historical events, connected as they were to his completion of specific buildings as a contractor-engineer-inventor.[340] The Bossut-Masurel textile factory warehouse completed by Hennebique in 1892 in the city of Roubaix, near Lille, appears to have encapsulated,

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[338] Clausen, 266.
[339] Reinforced concrete was certainly used for the basement of *La Samaritaine Magasin 2* and the under-street walkway that joined it to the original store. Much more was used after the First World War in the extension of the building to the banks of the Seine *Rive Droite*. Louis Escande, ‘Les Grands Travaux de La Samaritaine (Suite)’, *La Technique Des Travaux*, December 1933.
[340] 1892 was also the year in which Edmond Coignet, the son of French inventor François Coignet, lodged a patent for his own improved materials-system described more fully in Section 1.

if not even informed, key aspects of the novel reinforced concrete system described in these early industrial patents (see the case study of the building in Chapter 1).

Two issues are examined at this stage. The first is whether there was in fact a completely separate building design revolution for novel reinforced concrete and cement systems, with a different chronology and context to it that was clearly distinguishable from the preceding phase of increasing employment of iron and steel systems in construction. Keeping the whole period as one revolution stems from a number of positions. Firstly, you would not expect revolutions in science, engineering or building design to last a precise period of twenty-five (1864-1889) or twenty-two years (1892-1914), more likely they were much smoother and longer-lasting. Historical revolutions, whether political or industrial or linked to key causal events such as assassinations, riots or inventions of specific machines, are more complicated than neatly setting specific chronologies – how ever one tries to do this, there will always be a certain amount of 'fuzziness' within the choice and spread of dates. Addis confirms this in a book chapter examining the importance of nineteenth century engineering design of iron in British construction, where he points to the different forms of iron adapted to different structural requirements and combined with each other and other materials such as timber, glass and concrete to create a complex overall web of change.[341] Legault re-emphasised the case, initially outlined in his 1997 doctoral thesis, for considering that both novel iron and steel *and* reinforced concrete and cement structural systems followed the same building design path in France before First World War. Discussions took place with Paul Cottancin organised by French architects and engineers in the year the inventor lodged his first patent for his *ciment armé* system, coinciding with the 1889 *Exposition Universelle* in Paris; these talks used iron as the key reference material for technical judgements of the novel materials-system.[342]

Legault then points to the year 1895, which was three years after Hennebique's first key patents in Belgium and France (my chosen watershed year); in that year a series of articles were published in the respected journal *L'Architecture* by Louis-Charles Boileau in defence of *béton armé* as the new construction system of choice for his fellow French architects. Boileau had become thoroughly familiar with the use of iron in construction under his father Louis-Auguste, and as already mentioned, both were involved in the design and

[341] Bill Addis, 'The Soul of Iron and Its Revelation in Construction', in *Konstruktionssprachen* (De Gruyter, 2020), 61–72.
[342] Legault, 'Between the Visible and the Legible. Iron and Reinforced Concrete in Fin-de-Siècle France', 246.

build of the extensions to *Le Bon Marché* department store in Paris. Louis-Charles, who was editor of *L'Architecture*, had become a champion of François Hennebique's system, and per Legault, within his campaign to promote it amongst his peers he also pushed for a classicist approach to French architecture; this opposed the contrasting rationalist approaches of his architectural rival Anatole de Baudot, a direct disciple of Viollet-le-Duc. Boileau had already written in a 1890 *L'Architecture* article that rationalism as expressed by the opposing camp was about favoured structural systems, at the expense of decoration, and that its greatest advocate, Viollet-le-Duc, who he suggested had followed in the footsteps of Labrouste, was not well-known for his modern architectural accomplishments – his mantra had been that decoration should derive from the construction method, which rationalists believed had prevailed in the thirteenth century, claiming that this alone could inspire a logical modern architecture for the nineteenth century:

> The system which the master of Gothic rationalism thought logical par excellence consists – it cannot be repeated too much, because it is one of the reasons for the insignificance of his essays on modern architecture – in the exclusive use of frames as a constructive and decorative means. And this is understandable, because it is only there where the system applies in full.[343]

Returning to the first of Boileau's 1895 articles about the novel reinforced concrete and cement systems, he began by critiquing Cottancin's *ciment armé* system favoured by his antagonist de Baudot, for its lack of technical precision; against which he then presented what he considered to be the more acceptable *béton armé* system:

> The results [of Cottancin's system], appreciable for ordinary spans of floors or attic surfaces, seemed rather to derive from empirical formulas; it was not possible to deduce precise data for works of any span subjected to any load … This is, of course, a very important point; we believe it to be resolved by the new system, the so-called Hennebique system which we are going to discuss.[344]

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[343] Louis-Charles Boileau, 'Le Rationalisme Gothique et La Raison Classique', *L'Architecture* 3, no. 2 (January 1890): 13–15, 14. « Le système que le maître du rationalisme gothique a cru logique par excellence consiste - on ne saurait trop le répéter, parce que c'est un des motifs du peu de portée de ses essais sur l'architecture moderne - dans l'emploi exclusif des ossatures comme moyen constructif et décoratif. Et cela se comprend, parce que c'est là seulement ou le système s'applique intégralement. »
[344] Boileau, 'Le Ciment Armé. Nouvelle Methode d'Application. Suite.', 269. « Les résultats, appréciables pour des portées ordinaires de planchers ou de surfaces de combles, semblaient plutôt dériver de formules empiriques; on ne pouvait pas en déduire des données précises pour des ouvrage de portées quelconques soumis à n'importe quelles charge … C'est évidemment là un point très important; nous ne croyons résolu par le nouveau système, dit système *Hennebique*, dont nous allons parler. »

Boileau was reiterating his own arguments (paraphrased earlier in this chapter) about the need for iron building framing to stay invisible to the observer when viewing the design outcomes of the nineteenth century French architect.[345] The *béton armé* system was hence a logical extension, in the form of new reinforced concrete and cement systems, of Boileau's thinking about iron. Cottancin's and de Baudot's rationalist approach was designed to celebrate the dominance of a building's structure, recreating Gothic cathedrals at the expense of a more relevant approach taken by truly modern architects such as Boileau. Épron noted, correctly, that Boileau had within the same logical thread compared the non-monumental *immeuble* at 1 rue Danton (see the case study of the building in Chapter 4) with the monumental church of *Saint-Jean de Montmartre* also in Paris by de Baudot, which had employed the Cottancin system.[346] Hennebique helped reverse the nature of the discourse from one about hiding structural metal within a plastic surround, to one that extolled the lithic qualities of the novel materials-system; and he then extended the discussion to how one could make monolithic reinforced concrete structures more visible without even referencing the hidden metalwork. This may have suited the French inventor's own promotional purposes, designed to boost his design commissions. However, brilliant new technical designers with more of an architectural perspective, such as Auguste Perret and Henri Sauvage (who both *did not* use Hennebique's *béton armé* system) would soon put their best efforts into providing a more nuanced approach, one that restored the delicate balance between metal and artificial stone – they would be followed in France by other technical design specialists in the novel materials-system, though more so after the enforced break of the Great War.

Specifying a chronology and staging of the metallic building design revolution matters. It was useful to the key outcome of this doctoral research, the historical mechanism described in the next chapter, that the thesis has adapted from Addis's theoretical approach to a engineering design process (the Design Procedure) and his use of a Design Revolution historical model. This approach had to be refined by including all three of the key building design and construction professions (architect, engineer and contractor), rather than focusing as Addis does principally on the role of structural engineers, important as they were. It was also helpful to employ

[345] Mead quotes Boileau as saying in 1876: "I think one would gain a lot of precision and truthfulness by adding that the true, in architecture as in all the arts, is nothing more than the apparently true; that is to say, it is not the intrinsic qualities of materials – their true nature – that must determine their forms, but rather the apparent qualities by which they present themselves to the eye – their apparently true nature." Mead, *Making Modern Paris. Victor Baltard's Central Markets and the Urban Practice of Architecture, 247*.
[346] Epron, *Comprendre L'Éclectisme*, 287-8.

'process tracing' as a tool to filter potential example historic buildings and group them into two typologies, so that, as will be seen in Chapter 6, a historical mechanism could be produced that would help describe the influence of reinforced concrete and cement systems on *Belle Époque* building design. The case therefore stands for a single metallic building design revolution that 'began' in 1864 and encompassed iron, steel and later reinforced concrete and cement systems, of which the maturation of Hennebique's *béton armé* system from 1892 onwards shaped a second stage.

The year 1892 might possibly be extended backwards as far as the 1870s and 1880s to include Hennebique's initial thinking about the use of concrete with reinforcing iron framing, as well as take more account of earlier developments by his compatriots Coignet, Monier and Cottancin, or even by inventors further afield in Germany, Britain or the United States. It might also be extended forwards, perhaps to 1897 as the year Hennebique updated his patents to fully describe the pillar, beam, slab system with its additional internal components such as the angled rebars and inverted hoops; or to 1900 as the year of the Paris *Exposition Universelle*, when the city would show the world the progress France has made in the use of its novel reinforced concrete and cement systems for building design and construction (though not necessarily very visible from the outside). 1892 is a reasonable compromise between the earlier and later dates; it is only three years after the 1889 *Exposition Universelle* that, while it had marked the triumph of iron and steel in French construction, showed this triumph in the form of monumental, temporary structures as opposed to non-monumental, urban buildings. However, as we have seen, purely iron and steel approaches to building framing did not simply disappear from practice with the 'start' of stage two.

Case study: Parisian immeubles with decorative ceramic facade cladding

The *immeuble* at 9 rue Claude-Chahu in Paris was designed between 1902 and 1903 by the then unknown young French architect Charles Klein (1873-unknown), whose architect father, William, who had built the adjacent property. Klein junior had employed the *béton armé* system using the same experienced Hennebique *concessionnaire*, Louis Roquerbe, who had worked on the *immeuble* at 1 rue Danton (see the case study of the building in Chapter 4). It was built on an irregular corner plot owned by the architect's family (Figures 3.4 (a) and (b)).

Figures 3.4 (a) and (b): The immeuble at 9 rue Claude-Chahu (Klein, 1903) during construction showing the béton armé system building skeleton (left) and the decorative ceramic facade cladding that hid it after completion in 1903 (right). (076 Ifa 1/3. CNAM/SIAF/Cité de l'architecture et du patrimoine/Archives d'architecture contemporaine & Construction Moderne 1903)

The building is still to be found in the western Parisian district of Passy, originally opened up for urban development from 1890 onwards and as result expanding rapidly, with rue Claude-Chahu already completed in 1891; a building permit for a six-storey apartment block was submitted to the municipal authorities in March 1902.[347]

In May 1903 an anonymous piece on the completed *immeuble* was published in *La Construction Moderne*. It noted how the construction of Parisian *maisons de rapport* had undergone a major transformation in the preceding years, as novel materials permitted the radical modification of structures and their decorative facade cladding:

> The use of reinforced concrete, the Hennebique system, does not lead to over-simplifying the works, and to a very particular development of the site … The building faithfully interprets, with great artistic

[347] Gillet, 'An Iron-Mounted Stoneware Façade in Paris: Charles Klein's Apartment Building at Rue Claude-Chahu 9'.

sense, the drawings and designs of Mr. Klein, whose original work is thus shown to its full worth.[348] (Figure 3.5)

Figure 3.5: The immeuble at 9 rue Claude-Chahu, Paris (Klein, 1903) today showing the beautiful condition of the decorative facade with ceramic cladding. (Nick von Behr)

The account tells us that the construction phases started with the monolithic reinforced concrete skeleton, set on foundations. Large masonry interior walls containing the chimney shafts were built separately. The final phase saw the construction of a dual-skin exterior wall facing the street, including a thin interior part of standard bricks, to which was fixed the exterior part, made of thick blocks of ceramic stoneware. An air-cushion between the two skins provided temperature insulation. The stoneware skin was connected through a

[348] 'Maison, Rue Claude-Chahu, A Paris', *La Construction Moderne* 8, no. 31 (May 1903): 365–66. «L'emploi du béton armé, système Hennebique, ne conduit a de grandes simplifications dans les travaux, et à une marche toute particulière du chantier … Cette maison a interprété fidèlement, et avec un grand sens artistique, les dessins et maquettes de M. Klein, dont l'œuvre si originale est ainsi mise en pleine valeur. »

matrix of vertical and horizontal metal sections to the brick skin. The floors were each formed from a single slab of cast reinforced cement 0.10m thick, each calculated to withstand a load of 300kg per square metre. The total built area was 289 square metres and the rear courtyards required by revised Parisian street regulations 57 square metres. Each floor contained two apartments with main rooms having a street outlook. The stoneware decoration was both sculptural and polychromatic.

Louis-Charles Boileau pointed out publicly later in 1903 in *L'Architecture* the similarity between the dual-skin system used at 9 rue Claude-Chahu and Cottancin's system for exterior walls, where ceramic cladding was also attached (see Chapters 1 and 2).[349] Boileau noted Klein's clever use of the interior plan for the building and its "picturesque and intelligent way of meeting all the needs of access and lighting in the smallest possible space."[350] He included a description of the structural aspects of the building where the *béton armé* system was employed, singling out the small cross-section columns and beams that were embedded in either the walls or in spaces parallel to them, as well as the reinforced concrete floor slabs that were as strong as the joists and matrices of iron floor. Boileau also noted that the street facades were composed of interior walls constructed using brick infills mounted between reinforced concrete posts.[351] He complemented both Klein and the ceramicist Louis Müller on their use of ceramic stoneware for the decorative features, which he felt contributed to the aesthetic aspects of the street facade and which he believed combined well Gothic and Classical architectural genres.[352] A fortnight later, in a continuation of his commentary in *L'Architecture*, Boileau expanded on his views about the use of lithic cladding materials in contemporaneous buildings, including the *immeuble* at 9 rue Claude-Chahu:

> Ceramic stoneware, taken in itself, does not have to be treated as well as actual stone, so as to provide contoured lines or carved ornaments, which are softer or coarser than the same decorations executed in stone … Mr Cottancin would ask me to point out that the provisions used on Rue Claude-Chahu for ceramic stoneware construction have no analogy with the system he himself uses.[353]

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[349] Louis-Charles Boileau, 'Causerie. Art et Pratique', *L'Architecture* 16, no. 32 (August 1903): 311–14.
[350] Boileau, 311.
[351] Boileau, 312.
[352] Boileau, 313.
[353] Louis-Charles Boileau, 'Causerie. Art et Pratique. Suite et Fin', *L'Architecture* 16, no. 34 (August 1903): 331–34, 334. « La poterie de grès, prise en elle-même, n'a pas à être traitée ainsi que la pierre, de façon â fournir des lignes profilées ou des ornements sculptés, celles-là plus molles, ceux-ci plus veules ou plus grossiers que

As Boileau indicated at the end of his piece, Paul Cottancin had declined to take the original bait, not raising objections about the use of a similar approach to his own double-skin walling – perhaps he had already been chastened by an unsuccessful breach of patent legal suit against François Hennebique over the course of 1901-2.[354]

Le Béton Armé published an anonymous article on the building at the end of 1903, describing additional features of the building not already covered by prior commentary; this included the setting back of the top floor from the street facade, which made it possible to provide a continuous balcony at that level:

> A central bay window rises in the form of a turret crowned by a dome. The attic floor at the top of the building, is formed, like the dome, by a section of reinforced cement covered with flat tiles in a fish-scale shape … A roof-terrace covers all this, whose ornamental details can be admired as a model of good taste and artistic sense.[355]

Many years later, Peter Collins used the *immeuble* at 9 rue Claude-Chahu as a comparator for the more famous *immeuble* at 25b rue Benjamin Franklin, completed slightly later in the same district of Paris (see Chapter 6). While noting that Charles Klein had once studied with the other architect, Auguste Perret, Collins honed in on the specific connection between the two *immeubles*: the buildings were only four hundred yards apart and therefore Collins speculated that Perret must have prepared his own designs having been simultaneously influenced by the construction approaches used by Klein.[356] Legault subsequently referenced the wider structural aspects of Klein's building, observing:

> … despite a cost still higher than stone, the use of decorative stoneware appeared as the natural complement to reinforced-concrete construction … In this project, the reinforced-concrete … was

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les mêmes décors exécutés en pierre … M. Cottancin me prie de signaler que les dispositions employées rue Claude-Chahu, pour la construction en poterie de grès, n'ont pas d'analogie avec le système dont lui-même fait usage. »

[354] Procida, 'Paul Cottancin, Ingénieur, Inventeur et Constructeur', 603.

[355] 'L'emploi Du Béton Armé Dans Le Bâtiment La Maison de La Rue Claude-Chahu', *Le Béton Armé* 6, no. 67 (December 1903): 101–3. «Un bow-window central s'élève en forme de tourelle que couronne un dôme. L'étage mansardé qui termine la maison, est formé, comme le dôme, par un pan de brisis en ciment armé, revêtu de tuiles plates en écailles de poisson … Une terrasse couvre tout cet ensemble dont les détails ornementaux peuvent être proposés comme un modèle de bon goût et de sens artistique. »

[356] Collins, 180-1.

> construed as an auxiliary building system which enabled the development of the modern decorated wall.[357]

Gillet used the *immeuble* at 9 rue Claude-Chahu as one of five detailed case studies for his doctoral research, with a new analysis of the ceramic cladding, the particular focus of his study. He noted that there was little harmony between the format of the stoneware wall modules and the dimensions of the reinforced concrete skeleton. He also ascertained that while the stoneware blocks used for the third, fourth and fifth floors were of the same type as those used for the construction of the lower floors, the former had a lighter tint and smoother surface, due to differences in temperature and atmosphere in the oven used to fix their glazing.[358] Gillet went into considerably more detail about the positioning and fixing of the ceramic stoneware, unsurprising given his prime research interest in the technical and aesthetic aspects of Parisian ceramic-faced cladding systems at the end of the *Belle Époque*. He concluded his analysis of the *immeuble* at 9 rue Claude-Chahu by maintaining that, in effect, a separate structure was created by the exterior dual-skin wall:

> The pieces of stoneware then erected on the metal rods, the workers filled their cells with a fluid cement specially prepared for this purpose. After the cement had been introduced, the facade was transformed into a monolithic reinforced concrete structure in which the network of metal rods acted as reinforcement while the stoneware played the role of lost formwork.[359]

Gillet's conference paper of the same year, while concentrating entirely on the *immeuble*, took a broader approach to the design and construction of the building, though his focus remained on its use of stoneware cladding made by Louis Müller. He revealed that Charles Klein was only 29 years old at the time of designing the building and that the work was the only one definitely attributable to him.[360] As confirmed by a visit to the Hennebique files at the *Centre d'archives d'architecture contemporaine* in Paris (076 IFA 1/3), there are just two originals photographs of the building during construction and after completion, with no further details available on it. The ceramic stoneware facade and the interior vestibule were listed in the *Inventaire*

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[357] Legault, 'L'Appareil de L'Architecture Moderne: New Materials and Architectural Modernity in France, 1889-1934', 85.
[358] Gillet, 124-5.
[359] Gillet, 125-6. « Les pièces de grès ainsi dressées sur les tringles métalliques, les ouvriers remplirent les alvéoles d'un ciment fluide spécialement préparé à cet effet. Après la prise du ciment, la façade se métamorphosait en un ouvrage de béton armé monolithe dans lequel le réseau de tiges métalliques faisait fonction d'armature tandis que les poteries céramiques jouaient le rôle de coffrage perdu. »
[360] Gillet, 'An Iron-Mounted Stoneware Façade in Paris: Charles Klein's Apartment Building at Rue Claude-Chahu 9', 130.

Supplémentaire des Monuments Historiques in 1986. Gillet explained how Collins' original observation about a key relationship between the *immeubles* at 9 rue Claude-Chahu and 25b rue Benjamin Franklin had set off a subsequent academic debate on the timing of their construction. Soon after the publication of Collin's work, the French historian Françoise Choay had included the building in an article exploring the technical transition experienced by the architecture of the early 1900s, invalidating the interpretation of the building the British historian had provided. Gillet concluded his paper by defending Collins and stating unequivocally that the poor economics of this complex design and construction approach doomed it to long-term failure:

> Numerous works, including those of Martin Bressani, have since then established the precise building process of the project on rue Franklin and all state that Choay's remark that Perret's project was earlier than Klein's as unfounded, thus validating the version of events provided by [Collins] … The exorbitant costs, almost three times higher than the equivalent conventional Parisian dressed-stone facade, prevented this construction material from being widely adopted.[361]

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The other building in this case study, the *immeuble* at 185 rue Belliard in Paris, was constructed from 1910-13 by Henri Deneux, architect and building commissioner, and Gustave Degaine, the contractor, using an adaption of the Cottancin system (Figure 3.6). This small Parisian *maison de rapport* is an interesting building both for its use of the Cottancin system, as well as its geometric-style ceramic facade cladding, all in a small, irregularly-shaped plot owned by the architect. Deneux, who came from the provinces, had started in Paris in 1898 under the leading architect Anatole de Baudot, himself a disciple of Viollet-le-Duc; de Baudot was at the time Inspecteur Général des Monuments Historiques and a major proponent of the Cottancin system – he used it elegantly, though with some subsequent controversy, in the Église St Jean de Montmartre completed in 1904.[362]

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[361] Gillet, 131, 142.

[362] For more on de Baudot and his architecture see: Marie-Jeanne Dumont, 'The Philosopher's Stone: Anatole de Baudot and the French Rationalists', *Rassegna* 49, no. 1 (March 1992): 37–43; Beatrice Lampariello, 'Cells and Epines-Contreforts for a New Kind of Vaulted Roofing: The Church of Saint-Jean-de-Montmartre in Paris', in *Studies in the History of Services and Construction: Proceedings of the Fifth Conference of the Construction History Society*, ed. James W.P. Campbell et al. (Construction History Society, 2018), 357–68.

Figure 3.6: The street facades and bay windows of the immeuble at 185 rue Belliard, Paris (Deneux, 1913) today showing the unique geometric-style ceramic tiling. (Nick von Behr)

The first record of the building is to be found in Anatole de Baudot's posthumous work "L'Architecture, le passé, le présent" which appeared in 1916. He described the ground floor and the three floors above it that were intended for apartments, as well as the use of Cottancin's *ciment armé* system with threaded bricks, the latter covered with a cement plaster and decoration ceramic tiles:

> Everything was planned and directed in this construction project by the architect himself. So it does not have, either in its details or in its entirety, the banal and industrial aspect that we generally see in the street blocks which make Paris so monotonous.[363]

The contractor for the rue Belliard works, Gustave Degaine (1866-1928), who had completed St Jean after Cottancin left the project, had licence-free use of the system when the last patent expired in 1908. Degaine had, like Cottancin before him, become a member of de Baudot's *Union Syndicale des Architectes Français* (USAF); Deneux was to follow them both and subsequently become head architect at the Government office. Both architect and contractor expanded their reputations further after WW1, through Deneux's restoration work on Reims cathedral using reinforced concrete and Degaine's patenting of his own reinforced concrete system.[364]

We know from the designs submitted by Deneux to the municipal authorities that the rue Belliard *immeuble* used an adapted Cottancin reinforced concrete system for walls and partitions, with windows also prominent in the design (Figure 3.7).

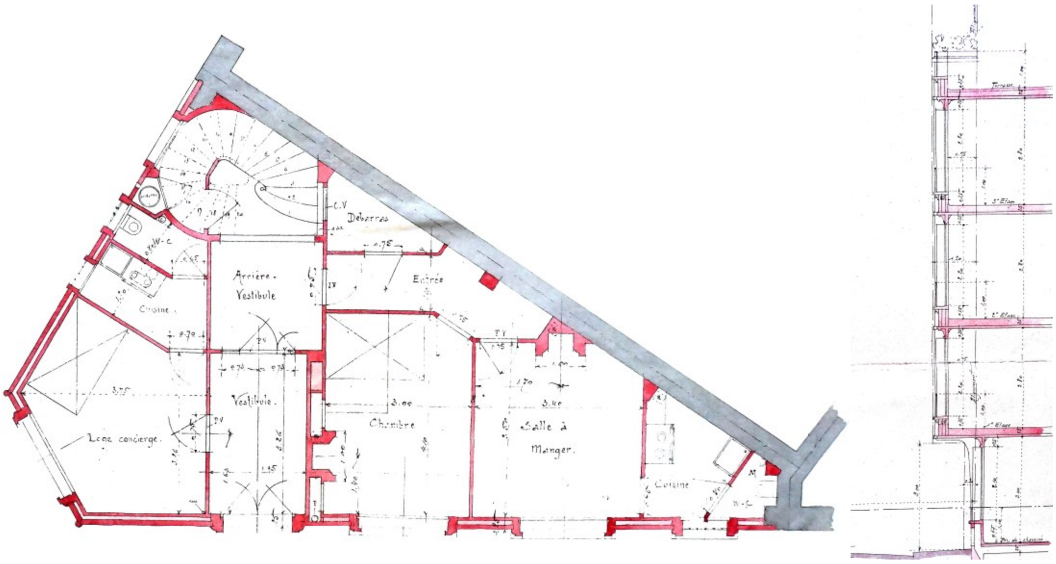

Figure 3.7: Original architectural designs for the immeuble at 185 rue Belliard, Paris (Deneux, 1913) with floor plan and section showing the use of the adapted Cottancin system and hollow exterior walls, 1910. (Archives de Paris, as adapted by Gillet 2020, p.220)

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363 Anatole de Baudot, *L'Architecture, Le Passé, Le Présent*, ed. Henri Laurens, 1916, 160. « Tout a été prévu, dirigé dans cette construction par l'architecte lui-même. Aussi n'a-t-elle pas, dans ses détails comme dans son ensemble, cet aspect banal et industriel qu'on constate dans la généralité des maisons de rapport et qui rend Paris si monotone. »

364 Gillet, 'Conception et Confection. Une Histoire Matérielle Du Revêtement Céramique Des Immeubles Parisiens (1900-1914)', 215–16, 230.

The exterior walls used a double layer envelope with air allowed to circulate in order to minimise any rain induced damp.[365] Gillet notes that the gap between the two walls was also probably used for heating and ventilation systems as well as water supply and drainage pipes.[366] A stand-out feature of 185 rue Belliard is its decorative facade with glazed ceramic tiling, though currently some of it is suffering from a century and more of degradation without major renovation. For his cladding Deneuve used a geometric pattern of tiles supplied by the French firm *Gentil & Bourdet*.[367] The predominant colour scheme is a creamy white, with some hints of orange, green and royal blue.

There are design plans for 185 rue Belliard in the Hennebique files held at the CAAC (BAH 076 IFA 1433/16 C/b/20/G/1), which explains the suggestion by Gillet that a *béton armé* system was supposed to have been employed originally (Figure 3.8).

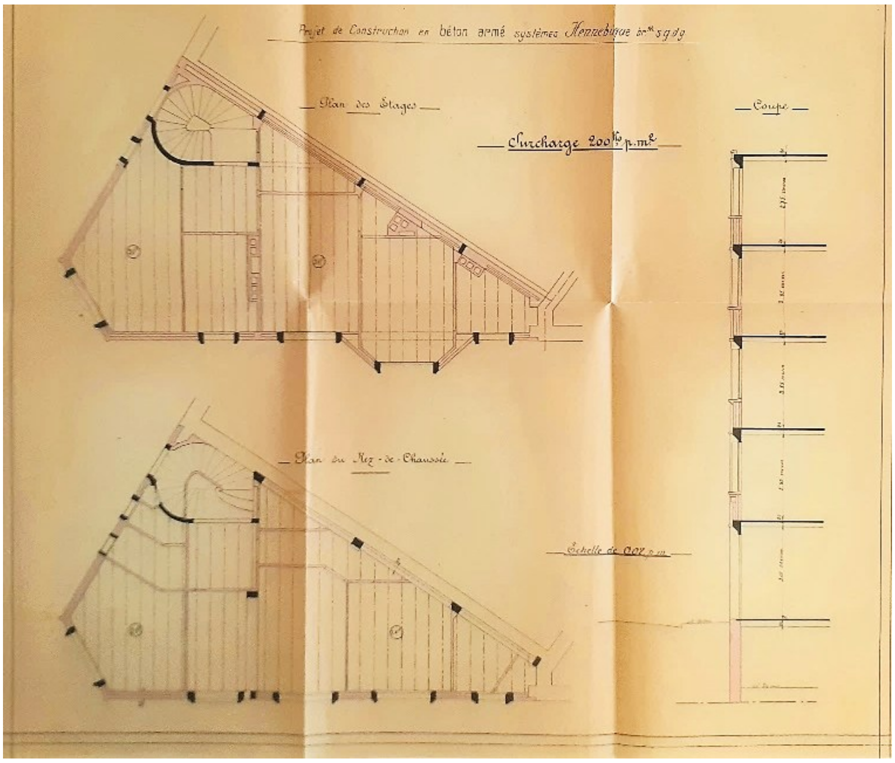

Figure 3.8: Hennebique structural design plans and section of the immeuble at 185 rue Belliard, Paris (Deneux, 1913), 1910. (076 Ifa 1433/16 C/b/20/G/1. CNAM/SIAF/Cité de l'architecture et du patrimoine/Archives d'architecture contemporaine)

365 Procida, 'Paul Cottancin, Ingénieur, Inventeur et Constructeur', 598.
366 Gillet, 'Conception et Confection Une Histoire Matérielle Du Revêtement Céramique Des Immeubles Parisiens (1900-1914)', 25.
367 Gillet, 230.

The Hennebique *concessionnaire* Ferrand-Pradeau had been asked by Deneux to draw up his own structural plans three months after receipt of the construction permit from the Parisian authorities. Gillet noted that the double bricks of the exterior wall could be seen on the floor plan, as well as the same four concrete pillars in the form of a trapezoid.[368] While inspecting the interior of the building, he identified three pillars sited along an axis running parallel to rue Belliard, which had not appeared in any of the plans, but which were clearly meant to reduce the extent of the floor spans. He saw on the final plans still held in the *Archives de Paris* (VO11-278, not accessible during this research project due to asbestos contamination) that the initial intention of Deneux as the chosen contractor for the project was for the whole of the column of bay windows on the main facade to be self-supporting. The Cottancin system did not seem to permit this type of extending structural support, because of the relative thinness of its floor slabs. A drawing in de Baudot's book in fact shows a careful extension outwards of the bay windows over the first few floors. Taking all these matters into consideration, Gillet decided overall on the attribution of the Cottancin system (as adapted by Degaine), rather than the *béton armé* system, for the building's skeleton. There seems no reason to contradict this assessment:

> … the presence of a file on the building in the Hennebique archives must not necessarily lead to a systematic attribution, but simply attests to the participation of one of the network's concessionnaires in the call for tenders.[369]

Case study: Four buildings in a new urban design approach

The following case study includes four commercial and administrative buildings completed in Brussels, and in and near Lille, between 1900 and 1910 that exemplified a new approach to technical design using innovative reinforced concrete and cement systems; this was after an initial period of maturation for the novel materials-system during the second stage of a *Belle Époque* metallic building design revolution.

The Belgian architect Léon Govaerts employed the *béton armé* system for the building framing and floors of an extension to the rear of *Banque Brunner*, at 68 rue de la Loi (since renumbered to 78 rue de la Loi), Brussels, completed in 1900. The bank and its extension are still with us, together with the unique cupola roofing in the

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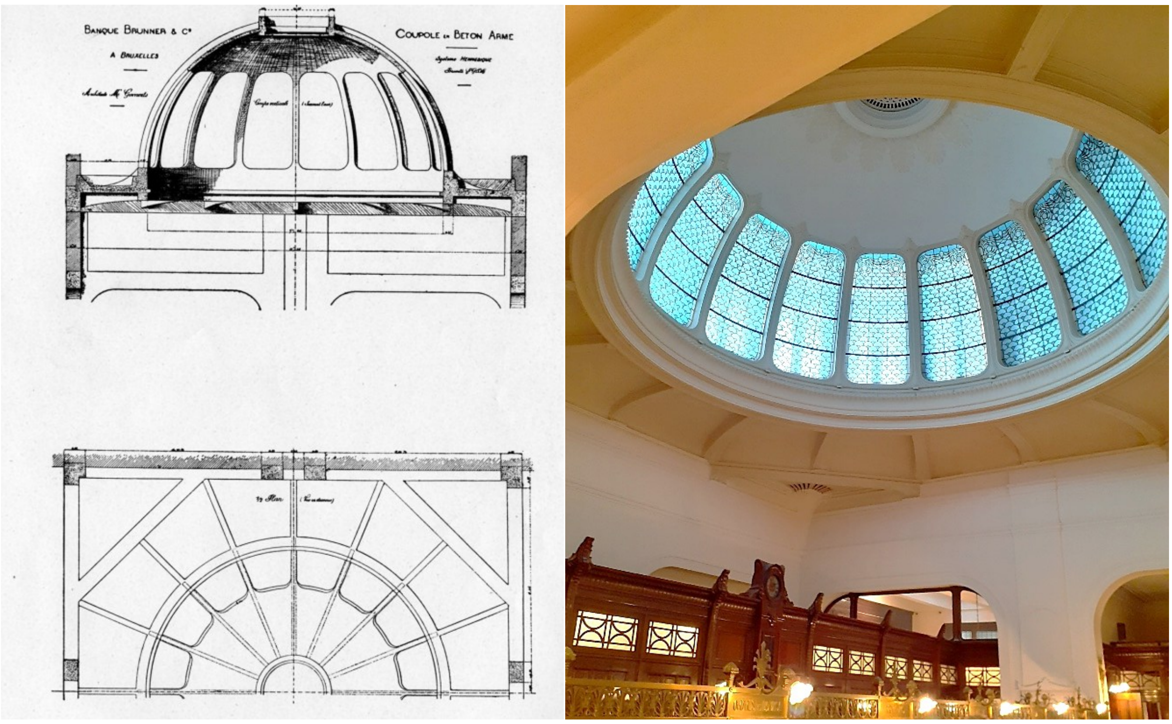
[368] Gillet, 228.

[369] Gillet, 230. « … la présence d'un dossier sur l'immeuble dans le fonds Hennebique ne doit pas conduire à une attribution systématique mais atteste simplement de la participation d'un des concessionnaires du réseau à l'appel d'offre. »

newly-created banking hall (Figures 3.9 (a) and (b)), though the whole building is no longer operating as was originally intended.



Figures 3.9 (a) and (b): Original design section and plan (left) and modern photograph (right) of the unique roof cupola in the extension to Banque Brunner, Brussels (Govaerts, 1900). (Le Béton Armé, Vol.3, No. 29, 1900, plates & Nick von Behr)

This unique use of the *béton armé* system may have been because Govaerts was a close acquaintance of François Hennebique, stemming from the latter's time in Brussels before he moved his expanding business back to France in the 1890s; during the late 1880s they had worked together on a design for a 300m timber tower in Brussels, to match the iron tower by Gustave Eiffel that was being constructed in Paris (Figure 3.10). This we know from a report of a brief toast by the Belgian architect at the *6eme Congrès du Béton Armé* held in Paris in February 1902, to which Hennebique had subsequently responded.[370] There is more about Govaerts as a highly successful Belgian architect under the other historic example building that was designed by him, the HBM at 32 rue Marconi in Brussels (see the case study of HBMs in Chapter 3). Hennebique was certainly very complimentary about his friend in the first recorded mention of the cupola during a 1900 Paris conference speech given by the French inventor:

> Here are now other forms of roofing: cupolas. We have before us the dome built at Banque Brunner in Brussels. The surface to be covered in plan was 11 meters by 11 meters approximately. The dome, with

[370] Paul Gallotti, 'Le 6ème Congrès Du Béton Armé', *Le Béton Armé* 5, no. 45 (February 1902): 113–15.

a diameter of about 7m 50, rests throughout its perimeter on a roof-terrace base. From the small sections shown in the photograph, you can judge what load coefficients we had to assume in order to counterbalance the forces. Besides, the appearance of this dome is very pretty; it is of perfect lightness and above all very well decorated by the architect, Mr. Govaerts.[371]

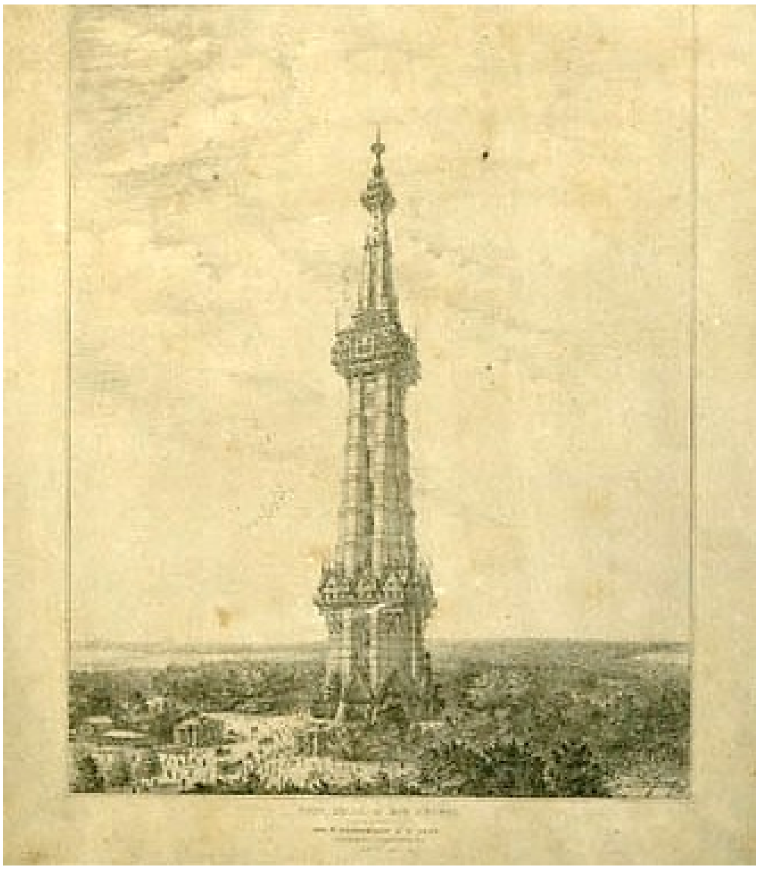


Figure 3.10: Drawing by Léon Govaerts of 'Projet de Tour en bois de 300 m', Brussels, 1888-1889. (6-J-142. CNAM/SIAF/Cité de l'architecture et du patrimoine/Archives d'architecture contemporaine)

Two years later, the Belgian state civil engineer Paul Christophe, who may well have attended that very same conference, used the *Banque Brunner* cupola as an example of a reinforced concrete dome in his comprehensive technical guide to new reinforced concrete and cement systems.[372] There are no separate references to the building in the *Travaux du Mois* or the annual summaries of works in *Le Béton Armé*. Not

[371] Flament, 'Quatrième Congrès Du Béton Armé. Séance Du Mardi Soir, 21 Août 1900'. « Voiçi maintenant d'autres formes de combles : les coupoles. Nous avons sous les yeux la coupole construite à la Banque Brunner, à Bruxelles. La surface à couvrir en plan était de 11 mètres sur 11 mètres environ. La coupole, d'un diamètre d'environ 7m 50, s'appuie, par l'intermédiaire de son périmètre sur une partie en terrasse. D'après les faibles sections que montre la photographie, vous jugez à' quel coefficient de travail nous avons à faire comme réaction pour les parties qui travaillent en console. Du reste, l'aspect de cette coupole est très joli ; elle est d'une légèreté parfaite et surtout très bien décorée par l'architecte, M. Govaerts. »

[372] Christophe, *Le Béton Armé et Ses Applications*, 213–14.

much more was known about Léon Govaerts and the extension to *Banque Brunner* until the completion in the early 1990s of a history of art degree dissertation by Basyn. He tells us from his accurate analysis of the original design specifications, still viewable at the *Archives de Bruxelles* (TP 14183), that the planned surface area of the newly-extended bank would measure 630 square metres, and that a courtyard of 115 square metres would have remained available; this would have more or less satisfied local hygiene regulations about the amount of external air space to be retained within Brussels properties (which was actually calculated at 125 square metres according to the required plot ratio).[373]

Both van de Voorde and Hellebois later referenced the structure briefly in their respective doctoral theses on Belgian reinforced concrete systems; the latter noted that the cupola was unusual for the *béton armé* system and was covered with a glass and wood external frame and that four other Brussels banks of the period had used reinforced concrete, but that this was in hidden places, for example floors or safety-deposit box rooms, rather than in the publicly-visible space of the banking hall.[374] The most recent analysis of the *Banque Brunner* extension was undertaken in 2015 as part of an overall historical and architectural assessment of the whole building, done prior to recent renovation work being carried out:

> The new building reflects the character of the Floral *Art Nouveau* style with its sinuous lines inspired by the plant world and stylized floral motifs, abundantly decorated. The entrance, as an extension of the hotel's carriage entrance, opens onto a vast square banking room covered with a dome. A hallway overlooking a marble staircase unites this rather luxurious space with the employees' offices located at the back and of less architectural interest.[375]

The building now operates as a central Brussels meetings venue in the heart of its European district. The remarkable cupola in the former banking hall still allows in daylight through its decorative glazing and wooden cover. Overhead admittance of natural light was common in banks, as there were few windows for security

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[373] Basyn, 'Léon Govaerts (1860-1930). Un Architecte de Transition.', 84–85.

[374] Voorde, 'Bouwen in Beton in België (1890-1975) Samenspel van Kennis, Experiment En Innovatie', 75; Hellebois, 'Theoretical and Experimental Studies on Early Reinforced Concrete Structures', 64.

[375] Patricia d'Oreye, 'Notes Pour Le Projet d'une Étude Historique de l'Hôtel de Maître et de La Banque Brunner 78 Rue de La Loi, Bruxelles' (MA2, 2015), 18. « Le nouveau bâtiment reflète bien le caractère du style Art nouveau floral avec ses lignes sinueuses inspirées du monde végétal et ses motifs floraux stylisés, abondamment décorés. L'entrée, en prolongation du passage cocher de l'hôtel, ouvre sur une vaste salle des guichets de plan carré et couverte d'une coupole. Un dégagement donnant sur un escalier de marbre unit cet espace assez luxueux aux bureaux des employés situés à l'arrière et d'un intérêt architectonique moindre. »

reasons, but this particular approach used the plastic advantages of the novel materials-system and so stands out – a more notable contemporaneous example, in Austria, was Otto Wagner's *Österreichische Postsparkasse* of 1906; while the main building framing used a reinforced concrete system, the banking hall reverted to more traditional iron and glass, though in a unique architectural genre for the time.[376]

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The second historic building in this case study is a wool-conditioning complex in Roubaix, near Lille, which was designed and completed in 1901 by the local architect Albert Bouvy and local contractor Auguste Pennel (Figure 3.11). The building took on other uses and was finally completely renovated in the early 2000s by the French architect Patrick Bouchain and his practice colleagues, and now operates within the Lille Metropole region as a culture-play centre called *La Condition Publique*.

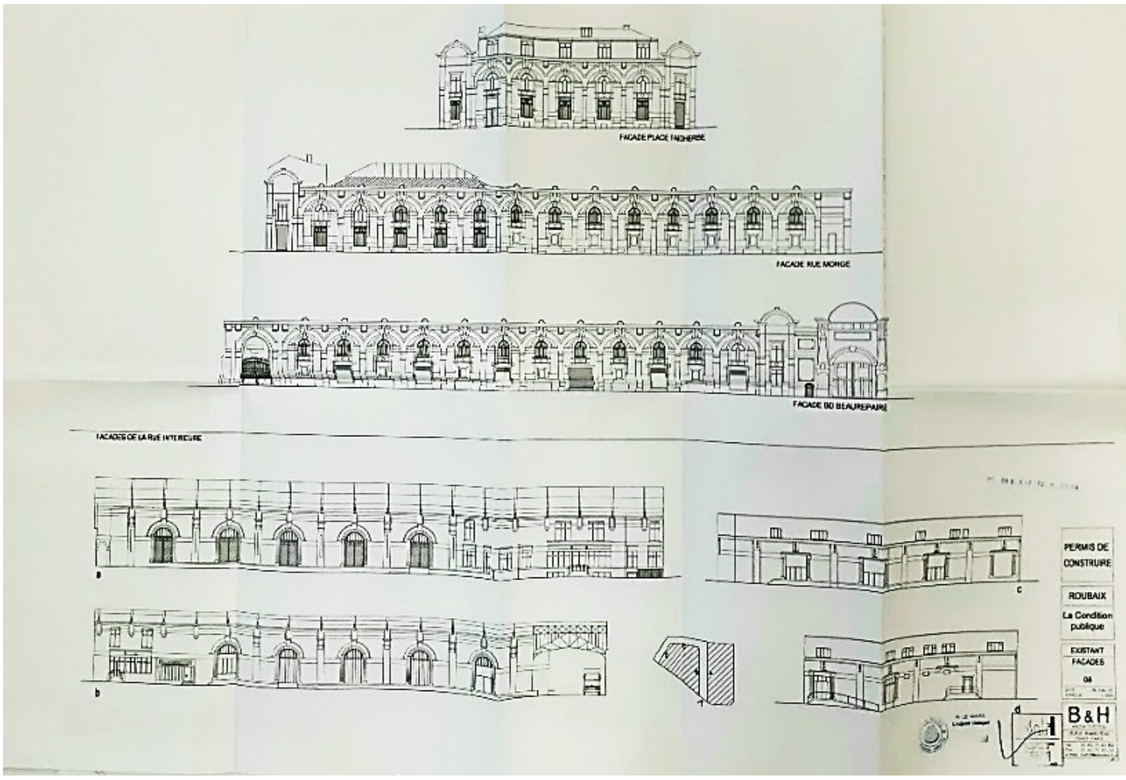


Figure 3.11: Elevations of existing former wool-conditioning complex, Roubaix (Bouvy, 1901), prior to its renovation by Patrick Bouchain and colleagues in the 2000s. (334 W5/1. Archives du Ville de Roubaix)

The building was Roubaix's second wool-conditioning facility, referencing existing premises there and in neighbouring Tourcoing, all to be found within one of France's major textile manufacturing regions of the late

[376] Christoph Thun-Hohenstein and Sebastian Hackenschmidt, *Post Otto Wagner. Von Der Postsparkasse Zur Postmoderne.* (MAK Birkhauser, 2017).

nineteenth and early twentieth centuries, as described previously. Bouvy took a different approach to the industrial architecture employed by his predecessors. He was probably influenced in this by his clients, the powerful Roubaix Chamber of Commerce, by his local contractor, Auguste Pennel, as well as his own architectural experience which had focused on a large number of 'polite' buildings in Roubaix and environs, many of which have been described in detail by Maury.[377]

It was always thought that the building was constructed using François Hennebique's reinforced concrete system, but my research has confirmed an initial suggestion by Singer in his Masters thesis; this implied that of considerably more importance than *béton armé* was the use of a system invented by the French engineer, Louis Coularou, about whom we know little.[378] The chosen contractor for the new wool-conditioning complex, Auguste Pennel, was a *concessionnaire* for Coularou in the Roubaix and Tourcoing area and he was selected for the work by early 1901. It is clear from original documents held at the *Archives Départementales du Nord* (79 J629-32, J629-34, J630-1 and J646-7), that the Roubaix Chamber of Commerce had specified the use of the 'fire-proof' Hennebique system in its original requirements for the building – which would hold large amounts of flammable wool for which powerful heating machinery was used in the wool-conditioning process. Bouvy had been selected out of a list of potential architects at the end of 1899, and he subsequently wrote to Chamber of Commerce in January 1900 about a meeting he had attended with them at which a decision had been made to adopt Hennebique's *béton armé* system for the roofing (Figure 3.12).

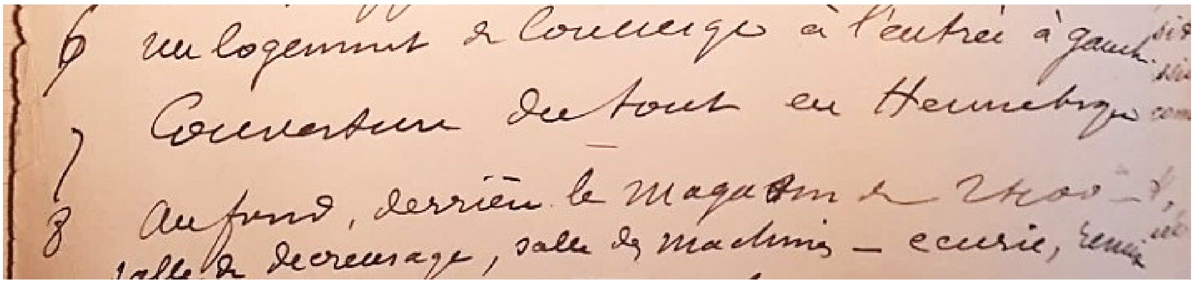
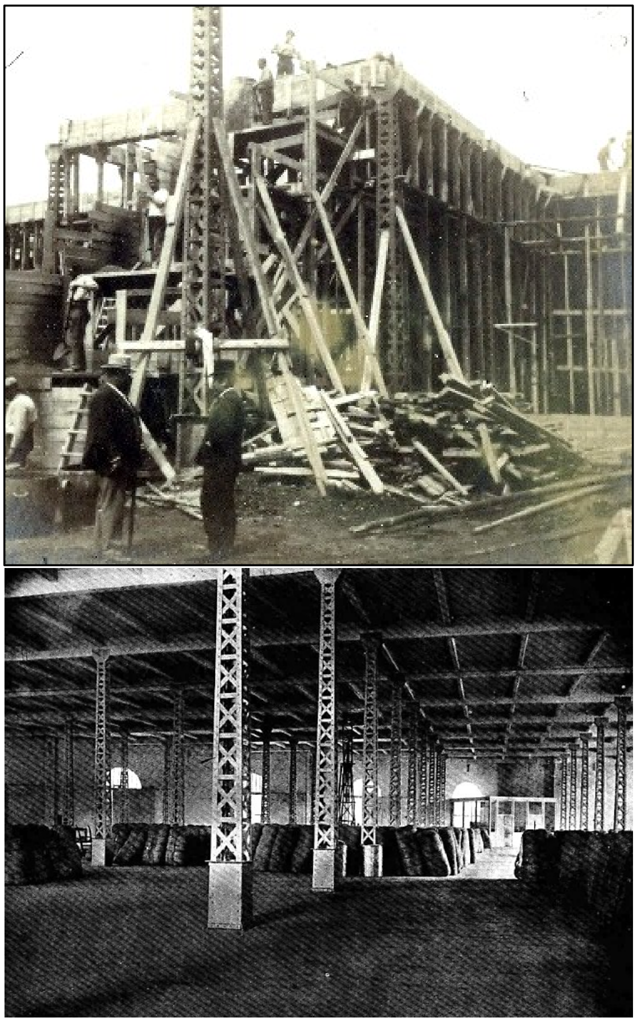

6 un logement de Concierge à l'entrée à gauche
7 Couverture de tout en Hennebique
8 Au fond, derrière le Magasin de ...
salle de decreusage, salle des machines — ecurie, remise

Figure 3.12: Extract from original construction programme for the wool-conditioning complex, Roubaix (Bouvy, 1901), showing point 7 on the planned use of Hennebique's béton armé system for the roofing. (79 J 632. Archives Départementales du Nord)

[377] Gilles Maury, 'Albert Bouvy. Redécouverte de l'oeuvre d'un Architecte', *Gens et Pierres de Roubaix*, February 2014.
[378] Guillaume Singer, 'Le Conditionnement de La Place Faidherbe à Roubaix' (University of Lille, 2001), 100.

This was written into the detailed building and structural specifications by the end of that month. The total cost of the works was put at 653,500 francs, a reduction of about 10 per cent on the original estimate due to savings on materials, with the reinforced concrete work alone estimated at 178,250 francs in July 1902.

We now know from a Louis Coularou sales brochure that $3000 m^2$ of reinforced concrete roof-terracing for the two large storage halls was built using his system.[379] A speculative justification for the move away from the *béton armé* system and towards the Coularou system may have been therefore partly due to potential cost savings, but also could have been connected with the technical issues involved in erecting and then using 39 trussed metal pillars to support the expansive roof-terracing (Figures 3.13 (a) and (b)).



Figures 3.13 (a) and (b): Contemporary photographs of the erection of (above) and subsequently the completed (below) trussed iron pillars and reinforced concrete terrace roof in the wool-conditioning complex, Roubaix (Bouvy, 1901). (Gilles Maury & Coularou Pamphlet, n.d.)

[379] Louis Coularou, 'Le Béton Armé et Ses Applications', *Pamphlet*, n.d.

It seems possible that Hennebique's system was not trusted to bear the dead load at the prescribed height of 8m and with the planned inclusion of an innovative internal gantry crane to move wool bales inside the halls. The story is similar to that of the later *La Cathédrale* at the Menier Chocolate Factory in Noisiel-sur-Marne (see the case study of 'daylight factories' in Chapter 2), where the *béton armé* system was explored initially, but not used for the final design and construction of the building – because there were suitable alternatives coming onto the market from the turn of the century, of which Hennebique was fully aware; after all, he simultaneously began a series of legal proceedings against potential rivals, described more in Chapter 1. The significant Motte-Bossut family of textile manufacturers which had dominated the city of Roubaix for a number of decades, would also use Coularou's system in the subsequent construction of a new velvet manufactory in 1903, so this might be considered evidence that the system had proved itself to local building commissioners.[380] The exterior facade of the current *Condition Publique* has attracted considerable architectural praise since its first completion and even more so after the renovation and conversion project by Bouchain and colleagues.[381] Polychromic bricks and ceramic tiles were originally used by Bouvy to give a colourful aspect to the facade, typical of the region's architecture as well as the *Art Nouveau* genre of Eclecticism that was emerging during the period (Figure 3.14).[382]

[380] Coularou.
[381] Patrick Bouchain, *La Condition Publique, Roubaix.* (Sujet-objet, 2004).
[382] Gilles Maury, 'Procédés Constructifs et Matériaux', in *Metamorphoses. La Réutilisation Du Patrimoine de l'âge Industriel Dans La Métropole Lilloise*, ed. Thierry Baert et al (Le Passage, 2013), 43.

Figure 3.14: The polychrome brick and tiling on the street facade of the former wool-conditioning complex, now 'La Condition Publique,' Roubaix (Bouvy, 1901). (Nick von Behr)

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The third building in this case study of a new urban design approach is the still extant *Entrepôt Royal B* import warehouse in Brussels. This was built in 1906 as part of the Tour & Taxis land once belonging to a German artistocratic family, and developed by the *Société du Canal et des Installations Maritimes* (SCIM) when improving Brussels Inland Port. Roof glazing set within iron-framed skylights permitted natural daylight to enter the heart of structure as it still does today; the building was renovated in 2005 and is now home to business offices and retail outlets (Figures 3.15 (a) and (b)).

Figures 3.15 (a) and (b): Entrepôt Royal B import warehouse, Brussels (van Humbeek, 1906) after construction in 1906 (left) and the renovated building today (right), showing the daylit atrium with cantilevered galleries made from béton armé. (076 Ifa 54/15. CNAM/SIAF/Cité de l'architecture et du patrimoine/Archives d'architecture contemporaine & Nick von Behr)

The contractor used for this project was one of the largest Hennebique licensees in Brussels, the family business of Louis de Waele, about which we know a fair amount through analysis of the company's records; the business was restructured as a joint stock operation after the death of its namesake in 1902 and from then on became a significant Hennebique *concessionnaire*.[383] We know less about the Belgian architect Ernest van Humbeek (1839-1907) and the Belgian engineer Jules Zone employed by the SCIM. The building had *encourbellement* or cantilevering of the internal floors to provide over-hanging walkways at the different levels of the daylit atrium.

The first record we have of the building is in a 1906 article in *Le Béton Armé* (itself quoting extensively from a Belgian journal) which stated that the project was finally completed despite complications with the building specifications. The piece went on to praise the competence of the architect, whose design had ensured that daylight would be admitted into every part of the structure:

> On all floors, galleries will give easy access to the non-combustible safes that constitute each of the twenty rooms forming a complete floor. Reinforced concrete stairs connect the four floors with each

[383] See Degraeve et al., 'Spatial Management of Contractors. An Analysis of the Industrial Sites of the Louis De Waele Enterprise in Brussels (1867-1988)'; Ine Wouters et al., 'Built to Stock. Versatility of Hennebique's Urban Warehouses in Belgium (1892-1914)', in *Building Knowledge, Constructing Histories. Volume 2 : Proceedings of the Sixth International Congress on Construction History (6ICCH), Brussels, Belgium, 9-13 July 2018*, ed. Ine Wouters et al. (CRC Press, 2018), 1383–91.

> other, and go to the upper roof-terrace, covered in volcanic cement and which supports two huge water tanks to put out fires.[384]

The writer remarked that as well as electrically-powered hoists and cranes allowing external access to the building for goods, eight powerful electric elevators were still waiting to be installed to raise and lower these goods between the various floors once they were inside the warehouse. The article noted that these goods were principally the valuable wine casks and barrels that Belgian importers brought in to the capital; and that the building would be illuminated inside with electric lighting to allow proper handling of such fine wares, whatever the outside light conditions, so presumably also at night-time. The account of the project finished with a review of some of the key numbers: total expenditure of approximately 1,6m Belgian francs (about £65,000 equivalent at the time of construction); the building materials used included about 60 million bricks and 15,000 tonnes of cement; the warehouse covered 10,000 square meters over five floors.

Van de Voorde included the *Entrepôt Royal B* import warehouse in her doctoral thesis on the history of concrete in Belgian construction.[385] She provided dimensions for the building, about 180 m long by 60 m wide, and clarified that the reinforced concrete components of the structure included columns, beams and arched floors in the storage rooms, galleries and consoles in the atrium. Van de Voorde noted the architectural elaboration of decorated brick walls and bluestone on the exterior. Hellebois' doctoral thesis also referred to the warehouse but provides no extra details on its use of the *béton armé* system.[386] Wouters and colleagues referenced the building in a paper about Belgian warehouses that were constructed using Hennebique's system. They noted concerns about overall loading, in that Jules Zone had requested the addition of a calculation note on the stirrups and larger reinforcement in some of the beams; and that the monolithic building framing and floors were similar to those employed in the reconstruction of other, since-demolished Brussels warehouses that had used vaulted beams as a structural solution.[387] Espion has subsequently

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[384] 'Le Nouvel Entrepôt de Bruxelles', 73. « A tous les étages, des galeries donneront un accès facile aux véritables coffres-forts incombustibles que constitue chacune des vingt salles formant un étage complet. Des escaliers en Béton armé font communiquer les quatre étages entre eux, et vont jusqu'à la terrasse supérieure, couverte en ciment volcanique et qui supporte deux immenses réservoirs d'eau assurant le service d'incendie. »
[385] Voorde, 'Bouwen in Beton in België (1890-1975) Samenspel van Kennis, Experiment En Innovatie', 64.
[386] Hellebois, 'Theoretical and Experimental Studies on Early Reinforced Concrete Structures', 65.
[387] Wouters et al., 'Built to Stock. Versatility of Hennebique's Urban Warehouses in Belgium (1892-1914)', 1390.

confirmed that the warehouse had foundation piling from the *Compressol* system, presumably because it was situated on softer ground next to the main quay of the recently-expanded Brussels Inland Port, another concern no doubt for Zone.[388]

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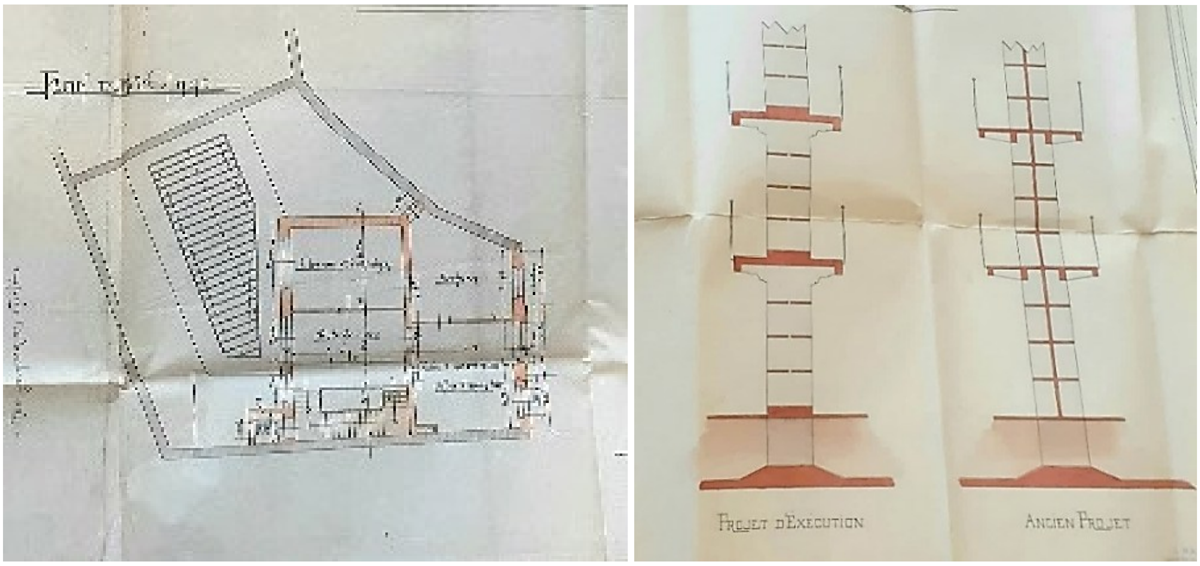
The final historic building in this case study of a new urban design approach is at the former site of the main depot for the *Archives Départementales du Nord* at 74 rue Jacquemars-Giélée in the city of Lille, designed by Léonce Hainez (1866-1916), who was Chief Architect of the *Département du Nord* (1905-14), and completed in 1910. The annex to the complex shares similar features to the much larger *Entrepôt Royal B* import warehouse in Brussels, but provides a slightly different approach and has not previously been the focus of any academic research. Hainez employed the *béton armé* system for the main document storage chamber, as the key concern was to prevent fire spreading from neighbouring properties or internally, as well as allowing enough natural light in from above, since there could be no side windows. There were no windows or exterior facade cladding for the main storage block, but light still enters the building through the roof glazing, the complex having been beautifully renovated and re-opened as an art and gastronomy collective in 2022. (Figures 3.16 (a) and (b)). The building used a similar reinforced concrete frame with cantilevered walkways as the *Entrepôt Royal B* warehouse, though it appears from a comparison of the design drawings that the latter is applied differently. The building's structure was first described in *Le Béton Armé* before its completion by the contractor, Charles Debosque-Bonte, who had earlier built the Six wool-combing mill in Tourcoing (see the case study on 'daylight factories' in Chapter 2, and particularly the dispute with its building commissioner, referenced in Chapter 4). Original design drawings showing the structural engineering proposed (Figures 3.17 (a) and (b)), and correspondence about the building, can be found at the current *Archives Départementales du Nord* (4 N 232 and 628, 32 J/428 and 429).

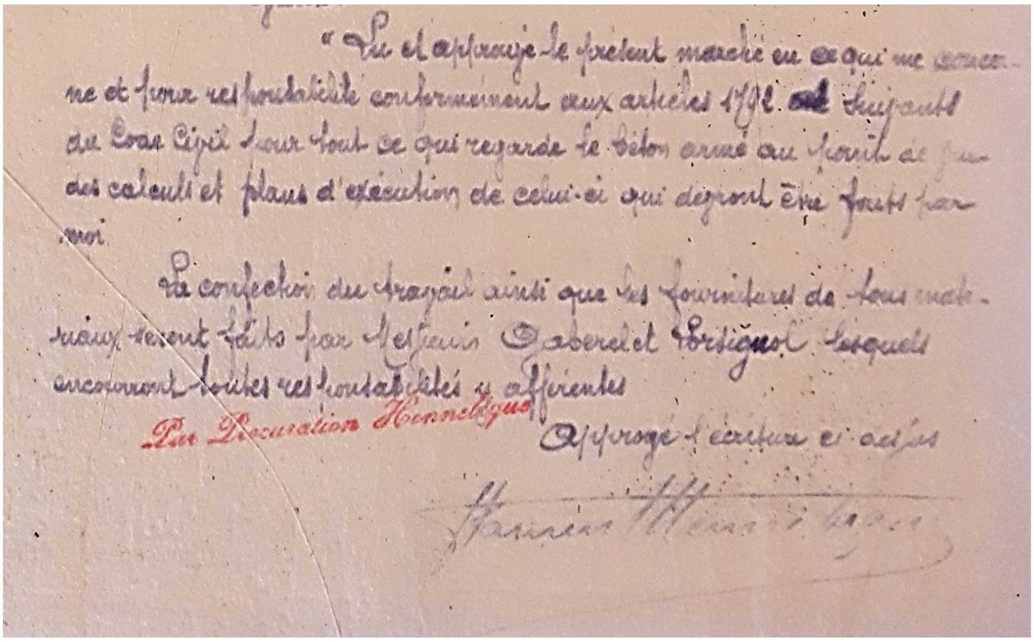
[388] Bernard Espion, 'La Renommée Internationale de La Belgique Dans l'Histoire Du Béton', *Bruxelles Patrimoine*, no. 30 (2019): 21.

Figures 3.16 (a) and (b): The annex of Archives Départementales du Nord, Lille (Hainez, 1910) during construction, 1908-10 (left) and the building before reopening in 2022 after renovation (right), showing the extent of daylight admission via skylights as well as the béton armé system cantilevered balconies. (076 Ifa 108/10. CNAM/SIAF/Cité de l'architecture et du patrimoine/Archives d'architecture contemporaine & Nick von Behr)



Figures 3.17 (a) and (b): Original designs for the Archives Départementales du Nord, Lille (Hainez, 1910) showing the whole complex site plan with glazed roof of the rear annex to the left (left), and interior sections of the annex's cantilevered balconies (right) c.1906. (4 N 628. Archives Départementales du Nord)

There are also original files on the annex held at the CAAC in Paris (BAH 076 IFA 108/10 and 1212/6). These include further design drawings as well as correspondence indicating key timelines in the construction project. For example, preliminary design began towards the end of 1906 coinciding with a public tender announcement in December, and construction work had started by March 1908. We also know that a range of contractors had bid for the work hoping to employ the *béton armé* system, for which they sought the engineering details from Hennebique's HQ in Paris. The files include a copy of a handwritten certificating letter signed by François Hennebique, about which at least one contractor complained due to its illegibility (Figure 3.18).


« Vu et approuve le présent marché en ce qui me concerne et pour responsabilité conformément aux articles 1792 et suivants du Code Civil pour tout ce qui regarde le béton armé au point de vue des calculs et plans d'exécution de celui-ci qui devront être faits par moi.

La confection du travail ainsi que les fournitures de tous matériaux seront faits par Messieurs Daberel et Brisignol lesquels encourront toutes responsabilités y afférentes

Par Procuration Hennebique

Approuvé l'écriture ci-dessus

Figure 3.18: Extract from handwritten letter by François Hennebique certifying his béton armé system, 8 December 1906. (76 Ifa 1212/6. CNAM/SIAF/Cité de l'architecture et du patrimoine/Archives d'architecture contemporaine)

We also know from the files that a number of competing contractors asked for discounts on their use of the *béton armé* system and that in the end Debosque-Bonte won the contract by offering a marginally lower price than his nearest competitor (see more on this in Chapter 4). According to the CAAC archives, a number of years after the project in Lille was completed, François Hennebique requested Mottez to send details to the business's Italian agent Porcheddu who had been commissioned to build archives for the City of Milan; to which Mottez duly replied in the affirmative, noting that the preliminary project for the Lille annex had been completely changed as it would have let in too little natural light. Debosque-Bonte went on the describe in more detail in his *Le Béton Armé* article specific components of the new building. These included the four floors of galleries, whose concrete columns rose to the roof-terracing, and whose 3-metre lengths were filled with cement shelves for the storage of archival material. The contractor also noted that the long skylights in the asphalt and concrete roof-terracing were each 2.5m long and illuminated a gallery of shelving, each floor of which had two balconies that sat 80cm across the supporting columns, cantilevered out 60cm on each side.[389] The next description of the building came in an anonymous 1910 article in *La Construction Moderne*.[390] The author tells us that two key ideas should inform the design of an archival depository: the preservation of

[389] Debosque-Bonte, 'Dépot d'Archives Départementales Rue Jacquemare-Giellé, à Lille', *Le Béton Armé* 12, no. 132 (May 1909): 75–76.

[390] 'L'annexe Des Archives Départementales Du Nord à Lille', 303-5.

documents by minimizing the risk of fire; and setting up an optimal system for storing and accessing the collections. The architect Léonce Hainez was then lauded for his use of the *béton armé* system to achieve these principal objectives and readers were asked to remember his previous designs of the Pasteur Institute and the city theatre, also in Lille. His response to limitations in the brief was deemed appropriate, particularly his proposed solution to the admittance of natural light, the description of which expanded on Debosque-Bonte's initial technical focus on the structural components. The floor to ceiling height on each floor was only 2.10m which allowed staff to access documents from the top shelves without using ladders – this in turn permitted less usage of available space and so more room for the daylight to penetrate through the galleries and into the whole building:

> The lighting is admitted through skylights in the roof, throwing a beautiful light which, although diffused through four floors, is still intense enough, even in the darkest place, so that the ground floor archives can even be accessed on the grey days of the northern region, without the help of artificial light.[391]

The author of the piece then went on to describe the novel archiving system designed by a M. Bruchet, the departmental archivist, as well as other technical aspects of the structure not already covered by *Le Béton Armé*. This included the fact that the rectangular reinforced concrete pillars of 0.14m x 0.80m section and a height of about ten metres that supported the whole building sat, via footings, on masonry shafts. We also find out that those freestanding galleries not supported by side-walling were calculated for up to 1500 kilograms of loading per square metre and that the reinforcements of the floors and pillars were made of both iron and steel with diameters varying from 5 to 35 mm.[392]

Chapter summary

The chapter started a new focus in the third and final section of the thesis on the building design context for construction using the novel materials-system during the *Belle Époque*. The chapter connected the technical aspects of building design to two stages of a metallic building design revolution which spanned the fifty years from 1864 to 1914. The first stage (1864-1889) involved the expanding use of iron and steel in place of more

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[391] 'L'annexe Des Archives Départementales Du Nord à Lille', 303-5. « L'éclairage est obtenu par des lanterneaux de la toiture, jetant une belle lumière qui, bien que diffusée à travers quatre étages, est encore assez intense, jusqu'a l'endroit le moins éclairé, pour que le service du rez-de-chaussée puisse se faire, même par les jours gris de la région du Nord, sans le secours d'une lumière artificielle. »

[392] 'L'annexe Des Archives Départementales Du Nord à Lille', 305.

traditional construction materials, exemplified by a number of, largely, monumental urban structures in and near Paris – these included the iron skeleton *Bibliothèque Nationale* (1868) and the steel and glass *Galerie des Machines* (1889). By the end of this first stage, the dominant approach to French and Belgian architecture that was known as Eclecticism, had begun to develop a highly decorative *Art Nouveau* architectural genre that had first flourished in Brussels with the design and construction of Hôtel Tassel by Belgian architect Victor Horta in 1893.

Brussels was the same city where François Hennebique had based his reinforced concrete operations until he moved to Paris in 1897, and the period coincided as if by chance with his initial technical breakthrough for the *béton armé* system, which begins the second stage of the metallic building design revolution. Hennebique was happy to promote the responsiveness of his invention to the demands of building commissioners for greater structural fire resistance, an improvement on existing metallic construction systems that clad iron or steel with substances that were claimed to be 'fire proof'. The only ties that are strongly evidenced between the French inventor and Belgian *Art Nouveau* architects seem to have been through a close personal relationship with Léon Govaerts, two of whose works are included as historic example buildings in the thesis. There appear to be stronger links between Hennebique and the works of French architects, engineers and contractors, whether or not they adopted the more aesthetically creative design freedoms of the *Art Nouveau* architectural genre. The chapter described a case study of two historic *immeubles* in Paris that had decoratively-clad ceramic street facades both protecting and hiding their reinforced concrete and cement skeletons. A further case study of four further historic commercial and administrative buildings completed between 1900-1910 all using the novel materials-system, exemplified a new urban design approach.

Chapter 6: A historical mechanism for technical building design

Chapter 6 identifies two *Belle Époque* non-monumental, urban typologies (Urban Industrial and Urban Housing) derived from twelve historic example buildings in the case studies in previous chapters. There are shared and contrasting features between these two typologies, which are considered in terms of the key factors that were at play within and between them. The typologies in turn contribute to the production of a historical mechanism designed to help answer the question: 'What was the influence of novel reinforced concrete and cement systems on non-monumental, urban building design in and near three *Belle Époque* cities?' The historical mechanism with its key components is described and it is then applied to a significant Parisian building, the *immeuble* at 25b rue Franklin by the Perret brothers (completed in 1904). The chapter ends by considering an issue raised in Chapter 4 about the professionalisation of specialist contractors and then examines the role of intermediary professionals in *Belle Époque* construction employing the novel materials-system.

6a. Identifying two typologies

Two typologies are derived from the case studies in the previous chapters that include twelve historic example buildings using reinforced concrete or cement systems completed between 1892 and 1914 in or near Paris, Lille and Brussels. The final choice of these case study subjects was originally determined from a starting list of more than 50 potential historic example buildings in and near these three cities (see Appendices for the full list). Some of these chosen buildings employed brick and masonry load-bearing and partition walls in conjunction with the novel materials-system, whether or not this made sense structurally, functionally or aesthetically. All but two of these buildings still stand today, although in differing conditions of original structural and decorative fabric. The definition of each typology is shaped by technical, societal and building design contexts in the previous chapters (see below); the typologies therefore connect back to the needs identified by the building commissioner, from which key structural requirements were derived in Sections 1 and 2, illustrated diagrammatically in the schematic at the end of Section 2 (Figure 2.1).

The first of the two typologies, Urban Industrial, uses historic examples from the case study in Chapter 2 of two French 'daylight factories' on the outskirts of Paris and Lille, as well as from the case study in Chapter 5 of four commercial and administrative buildings with a new urban design approach. The second typology, Urban

Housing, uses the three historic examples of HBMs in the case study in Chapter 3; the private *immeuble* at 1 rue Danton in Paris in the case study in Chapter 4, which employed a moulded cement facade cladding; and two other Parisian private *immeubles* in the case study in Chapter 5, each with decorative ceramic facade cladding.

An alternative to using two typologies to categorise a sample of *Belle Époque* design and construction would have been to find a 'sufficient' number of example historic buildings (whether in case studies or not), with a simple rule that too few of them would fail to capture the full extent of any key variations, and too many would dilute the possibility of useful comparative analysis. Instead, the two selected typologies are derived from twelve out of thirteen historic example buildings in the case studies, a pragmatic compromise between those two extreme positions. The case study of the Bossut-Masurel textile factory warehouse completed in Roubaix near Lille in 1892 (see Chapter 1) provides a shared starting point for both of the typologies rather than belonging to either of them – it was a building that was clearly industrial and commercial in function, with an emphasis on structural efficiency and fire resistance. At the same time it was used by Hennebique as a test bed for his developing *béton armé* system, that might be applied to other structural requirements, including daylight admission and even an element of street decor.

Urban Industrial typology

The description used for the Urban Industrial typology indicates key industrial design features that are considered, with the benefit of hindsight, to have gone beyond *Belle Époque* Eclecticism, including its *Art Nouveau* architectural genre. The key structural requirements in the Urban Industrial typology were to use reinforced concrete or cement systems to satisfy the building commissioner's need for a fire-resistant, structurally efficient building providing maximum operational space and admitting maximal natural light into the interior. Within the typology sit two French 'daylight factories' derived from the first North American industrial buildings constructed using reinforced concrete systems with predominantly glazed facade infills. As described in the case study in Chapter 2, the architectural typology of the 'daylight factory' had wider connotations connected to an International Modernist architectural trope that fully emerged after the First World War. The case study of the French 'daylight factories' illustrates a technical transition from the novel materials-system into truly monolithic buildings, producing a homogenous skeleton with the minimum sizes of reinforced concrete building framing and floors. This permitted the creation of more voluminous interior spaces where lighter and less frequent columns minimised the obstruction of manufacturing operations. In addition, larger windows maximised the limited daylight of Northern European latitudes, particularly during the long winter months. Such increased facade glazing would also minimise the use of artificial light, which was not only more expensive, but which, when associated with textile manufacturing within an internal environment replete with fine dust and machinery vapours, was more likely to set off rapid conflagrations if a gas flame or electric spark caught on highly flammable raw or finished materials. The increased natural light also provided efficiency benefits for the workers within the factory buildings, for example improving the visual inspection of the wool-combing process at Charles Six's new mill in Tourcoing, near Lille. At *La Cathédrale* in the Menier Chocolate Factory complex at Noisiel-sur-Marne, near Paris, the admission of more daylight not only assisted with chocolate manufacturing operations, but also allowed the many regular visitors to admire from galleries the hygienic operating process that used two enormous cocoa and sugar combining machines.

The Urban Industrial typology also incudes four historic buildings in the case study in Chapter 5 on a new urban design approach. These were the extension to a bank, a wool conditioning complex, an import warehouse and an annex to regional administrative archives. All of these buildings had to be made as fire resistant as possible in order to prevent, or at least minimise, flame damage to both the structure and, perhaps even more importantly, the valuable stored contents within them and this could be best achieved through the use of reinforced concrete or cement systems. Though not all monolithic, they were also structurally efficient buildings. The other principal need of their building commissioners was to maximise the admission of natural light into the buildings, which converted into a structural requirement shared with the 'daylight factory' examples in the same Urban Industrial typology, but within design restrictions imposed by their more urbanised locations. By contrast, the 'daylight factory' examples were entirely new, free-standing structures built in open space within a much larger manufacturing complex.

Urban Housing typology

The Urban Housing typology pioneered a transition into truly monolithic buildings that would become more commonplace in the interwar years with the rise of International Modernism as an architectural movement. Urban Housing is a typology derived partly from a case study in Chapter 3 of three *Habitations à Bon Marché* (HBMs) completed before First World War, one in Brussels and two in Paris, using reinforced concrete and cement systems at least in part. All three of these historic buildings (connected blocks in a larger complex in the case of one of them) were commissioned by philanthropic consortiums for the benefit of poorer tenants, a social housing function they continue to perform to this day, after extensive renovations. Relatively few HBMs using reinforced concrete or cement systems were actually completed before the First World War in France and Belgium, which makes the three historic buildings stand out. A higher cost at the time relative expense when compared to using brick for the building framing seems to have been significant – but there were also separate issues around the conversion from traditional masonry and timber to brick as the main load-bearing support for the building framing, as well as the lack of evidence for the use of iron or steel in HBMs, with very few exceptions during this period. The emphasis in the original HBMs was on the use of economic and novel building materials within crowded urban settings, taking the shape of more affordable, more spacious and more hygienic accommodation. The rise of private-led and state-sanctioned social and health-related movements described in Chapter 3, caused the establishment of organisations with largely altruistic motives. Some of their wealthier supporters, such as the Rothschild family, may have been undertaking a public relations exercise in the face of a growing socialist backlash, while others were simply keen to make at least a marginal economic return on their investments. Most of the architects they turned to were motivated by a genuine spirit of philanthropy and societal change and were considered some of the best of a new versatile generation. Henri Sauvage and Charles Sarazin designed many Parisian HBMs and private *immeubles*, one of which is the subject of a case study in this thesis.

In contrast to social housing alone, the Urban Housing typology includes three examples from two case studies of Parisian buildings (one example in the case study in Chapter 4 and two in the case study in Chapter 5) that were commissioned privately with accommodation designed for better-off occupiers; some of these actors may have owned the building and/or rented out its apartments *en bloc* as a *maison de rapport* primarily for investment purposes. The three private *immeubles* were at 1 rue Danton (1900), rue Claude-Chahu (1903) and rue Belliard (1913). These buildings each had distinct street facades that employed new approaches to the masking of monolithic reinforced concrete building skeletons. They continued the architectural theme of the previous century's Eclecticism in urban housing in the French capital, and when compared to the more restrained Haussmannian normality imposed during the Second Empire (see Chapter 4), these buildings collectively illustrate a greater creative design expression. The unusual design of the *immeuble* at 1 rue Danton in Paris raised a whole series of building design and construction questions, of which many have remained only partially answered, even with reference to the other historic example buildings. While the building was primarily intended as a showpiece to promote the *béton armé* system to representatives from around the world who were in Paris for the 1900 *Exposition Universelle*, François Hennebique also needed to operate his expanding business from appropriate premises. There were bound to be limits to his radical wishes as building commissioner.

Table 3.1 below compares the two typologies using the five key structural requirements, derived from building commissioner needs, described in the expanded schematic at the end of Section 2: fire resistance, structural efficiency, daylight admission, street decor and social attributes.

Table 3.1: The two typologies compared by their key structural requirements and design features

Typology	Reinforced concrete or cement systems	Fire resistance	Structural efficiency	Street decor	Daylight admission	Social attributes	Key design features in the typology
Urban Industrial	*béton armé*, *béton fretté* and Viennot, Coularou and Compressol systems	yes	yes	some	yes	no	Large windows and open spaces. Curved building corner. Roof-terracing. Cantilevered walkways and skylights. Coupole.
Urban Housing	*béton armé* (or derivative), Cottancin-derivative, Compressol and unknown systems	yes	yes	yes	some	yes	Bay and special windows. Roof-terracing. Lime-washing. Cement moulded, stoneware and ceramic tile facades. Polychrome bricks. External staircases. Dual-skin walling. Set-back balconies.

Table 3.2 in the Appendices provides a matrix of all twelve buildings from which the two typologies are derived, highlighting them against their connections with the reinforced concrete or cement systems used as well as any other standout technical design features.

6b. Comparing the two typologies

For the two typologies of *Belle Époque* building, the building commissioners with their specialist designers and contractors turned to novel reinforced concrete and cement systems. These allowed them to construct new non-monumental, urban structures within and near three major cities in France and Belgium. To do this effectively, the building designers and constructors needed to have enough confidence in their abilities and to possess the right specialist skills in the novel materials-system, as well as ensuring the finished building reflected the original design intentions. Specialist contractors equally needed to be able to turn the paper designs into executed structures that sufficiently met their expectations. They might have also needed to persuade building commissioners, architects and engineers to adapt their approaches to suit unforeseen technical problems uncovered along the way, with appropriate financial restitution for their additional efforts. All of these approaches defined the components of the historical mechanism described subsequently in this chapter.

The 'daylight factories', such as Charles Six's wool-combing mill in Tourcoing and *La Cathédrale* at the Menier Chocolate Factory in Noisiel-sur-Marne, provide us with a useful literal and metaphorical thread that connects with the other historic examples in the Urban Industrial typology, namely the admission of more natural light into commercial and administrative buildings for financial instruments, imported goods, wool and archival documents. We might ask whether the importance of daylight admission might also be applied to certain types of Urban Housing? The key difference, however, was between buildings that were situated in a central metropolitan environment and those that were built in a more remote setting, outside the reach of urban planners. Bay windows in apartments had come across the channel from Britain to France and demand to incorporate these in Parisian streets pushed against prevailing street regulations; only after the First World War did greater daylight conquer them, aided by the Modernist emphasis on bigger windows (see the 'daylight factories' case study in Chapter 2). Would this trend have happened if Le Corbusier had not used Gropius's photographs of North American industrial architecture from the pre-First World War Deutsche Werkbund publication and adapted them for his own architectural purposes, would the trope have still happened in another form? To test such a proposition one would need to consider examples from comparative American and European pre-First World War **and** interwar typologies, categorised according to the technical and aesthetic influence of their reinforced concrete systems. The best way to determine this effectively would be to undertake a study from the perspective of each side of the Atlantic, a 'Reinforced Concrete Mid-Atlantic', combining the initial thinking of Collins and Banham with that of subsequent researchers including Biggs, Slaton and Mortensen. Such an international comparison could bring in wider lessons from different cement-based systems that connected the USA with Europe and vice-versa.[393]

What does a direct comparison between the Urban Industrial and the Urban Housing typologies tell us? Fire resistance was a key structural requirement derived from the demands of *Belle Époque* building commissioners, one that might best be satisfied by employing the innovative reinforced concrete and cement systems of the second stage of a metallic building design revolution. Slaton has critiqued Banham's suggestion that fire resistance was a key building commissioner need for North American 'daylight factories', despite his coining the very name of the architectural typology with no reference to this structural requirement. She argues instead that in the United States at least, the continuing proliferation of wooden mill buildings implied that factory owners were satisfied with the slow-burning characteristics of the thick timber used to construct them.[394] This may well have been true on the other side of the Atlantic, it is less certain in Europe. Moreover, one of the key features in the majority of the historic example buildings in the Urban Industrial typology was the value and flammability of *the artefacts* stored inside these buildings, ranging from expensive alcoholic drinks, to raw or processed wool, to precious financial and archival materials.

During the Third Republic there was a move away from the regimented street facades set by Haussmann's strict planning approach to Paris begun in the 1850s, so far as the Urban Housing typology was concerned. As described in Chapter 4, encouraged by in-house and external architects, the Paris planning authorities used this opportunity to seek greater creative freedoms in urban building design within the flourishing *Art Nouveau*

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[393] A case study for one of these is Thomas Edison's invention of a poured concrete process for building monolithic block houses which was exported across the Atlantic to the Netherlands and then used in Belgium and France. Edison's technical solution to such monolithism is being researched at the time of writing. See Tom Packet, 'Concrete Proposals: The Reception of Thomas A. Edison's Monolithic Concrete House and Discussions on Mass-Produced Housing for the Working Classes in Pre-War Belgium, 1911-1913', in *Proceedings of the Annual Conference of the Construction History Society*, ed. James W P Campbell et al. (Construction History Society, 2023), 423–34.
[394] Slaton, *Reinforced Concrete and the Modernization of American Building, 1900–1930*, chap. 4.

architectural genre of Eclecticism. Two buildings from the Urban Housing typology were completed in the years immediately after 1902 when the revised Paris street regulations were published, but we might ask whether the HBM at 7 rue de Trétaigne (see the HBMs case study in Chapter 3) and the *immeuble* at 9 rue Claude-Chahu (see the case study of Parisian *immeubles* with decorative ceramic facade cladding in Chapter 5) were both really influenced by the regulatory changes, even though one provided social housing and the other private accommodation. There was a growing use of *redans*, setback floors and roof-terracing in Paris, as well as issues around the use of glass or clay bricks for facade infills and different types of facade cladding, which all went hand-in-glove with pressures for regulatory reform in the post-Haussmannian environment. Other buildings completed after the First World War suggest that the changes would have happened anyway due to the technical, social and professional, as opposed to the regulatory context for the novel materials-system. It seems less probable that these municipal regulations spurred the use of the novel materials-system during the *Belle Époque*. More likely it was the result of demand for existing metallic-based structural specifications, as already demonstrated. The actual dynamics between the structural form and the aesthetic appearance of buildings depended in any case on a multitude of factors. The *Art Nouveau* architectural genre of Eclecticism evident in buildings of the period seems not to have been directly related to reinforced concrete or cement systems and Gillet's is the only recently completed doctoral thesis that has begun to explore the specific relationship between specialist ceramic cladding used in *Art Nouveau* facades and the hidden building skeletons behind them that employed the novel materials-system.

By including buildings for both private accommodation as well as for social housing within the Urban Housing typology, a broader coverage is included than simply one or other facet of two distinctive commissioning needs. The former buildings, which housed better-off private tenants, employed the decorative features of facades as a respectable mask of the reinforced concrete or cement skeletons behind them. By contrast, the design and construction of social housing was derived from a need for affordable and hygienic accommodation for those who were at the opposite end of the societal hierarchy. All the historic examples included in this typology shared a common objective of providing non-monumental, permanent housing blocks within a 'typical' urban setting. A building in the Urban Housing typology may have already been extensively researched by others, as with Gillet's work on five Parisian private *immeubles*, two of which are included as historic example buildings in the case study of two Parisian *immeubles* with decorative ceramic facade cladding in

Chapter 5. The most valid approach was to cross-check and reanalyse the original research, adopting a different perspective whenever possible.

Gillet's doctoral thesis was primarily focused on the use of decorative ceramic facade cladding associated with the *Art Nouveau* architectural genre, but he had a subsidiary motive of connecting Parisian street decor to the visibility (or not) of reinforced concrete and cement monolithic skeletons, specifically by means of the external walls and their facades. Such an approach had been initiated by Legault in 1997 – the sweep of the current thesis is both technically and societally considerably broader than Gillet's, so more of a reversion to Legault, and more of an association with Traisnel's doctoral thesis on the technical aspects of external walls (see the Historiographical Framework). The two Parisian private *immeubles* are subsequently combined within the Urban Housing typology with the earlier private *immeuble* at 1 rue Danton, also in Paris, that instead had used decorative moulded cement on its facade; for *Belle Époque* commentators such an approach had represented a failure of the architect Arnaud's courage in undertaking satisfactory aesthetic design of the building incorporating the novelty of the materials-system employed (see the case study in Chapter 4). Subsequent retrospective analysis has given more credit to Arnaud's efforts within the limitations placed on him by Hennebique as the highly demanding client who 'owned' the technology. Nonetheless, better examples of architectural creativity in the face of the opportunities and challenges posed by the novel materials-system were the 'plain' HBM at 7 rue de Trétaigne by Sauvage and Sarazin (see the case study of HBMs in Chapter 3), also included in Urban Housing typology, and its contemporaneous private *immeuble* at 25b rue Benjamin Franklin by the Perret brothers (excluded from the Urban Housing typology, but on which the historical mechanism is used later in the chapter).

6c. Describing a historical mechanism

The historical mechanism in this thesis has been informed by and adapted from the 'Design Procedure' and 'Design Revolution' engineering-based historical models proposed by Addis (see the Historiographic Framework). These have helped identify two stages of a metallic building design revolution spanning the period of the *Belle Époque*. The first stage centred on the use of iron and steel (1864-1889) in monumental Parisian buildings, while the second stage centred on the use of new reinforced concrete and cement systems in non-monumental, urban buildings (1892-1914). Other theoretical models have contributed to this interpretation, while process tracing has been used to test the evidence from historical example buildings within technical, societal and building design contexts connected to the three major cities and their environs included in the thesis: Paris, Lille and Brussels. The historical mechanism captures the significance of a ‘daylight factory’ architectural typology, connected to pre-First World War North American reinforced concrete and glass factories and a subsequent International Modernist trope – as discussed in Chapter 2 and within the Urban Industrial typology described in the present chapter. The historical mechanism equally reflects the outcomes of a discussion of *Belle Époque* Eclecticism and its highly decorative *Art Nouveau* architectural genre in Chapter 5. The purpose of the historical mechanism is to help provide an explanation of historical causation framed by the question: ‘What was the influence of novel reinforced concrete and cement systems on non-monumental, urban building design in and near three *Belle Époque* cities?’ The mechanism also offers the opportunity to interpret historical causation in other case studies and historic example buildings set within similar research boundaries to those used in this particular doctoral research project. The historical mechanism is illustrated in the diagram in Figure 3.19.

1a Convert building commissioner needs into structural requirements: i. fire resistance ii. structural efficiency iii. daylight admission iv. street decor v. social attributes ⇨	1b Structural requirements shaped by early industrial standards for the novel materials-system: i. industrial patents ii. structural specifications iii. technical guidance FLOW PROCESS ⇨	1c Balance technology and aesthetics in the final design composition through: i. a coherent, novel materials-system (derived from 1a & 1b) ii. expressive freedoms iii. regard for communal standards
2a Professional confidence in technical design abilities	2b Specialist technical design and application skills	2c Completed build reflects the original design intentions
Mechanism describing the technical design process across two typologies of historic building that employed a novel materials-system		

Figure 3.19: Diagram illustrating the historical mechanism.

The historical mechanism has six components shown in the diagram as 1a,1b, 1c, 2a, 2b and 2c, all derived from the expanded schematic at the end of Section 2, but with refinements from the building design context in this final section. It should be noted that the importance of certain societal expectations for the novel materials-system has been reduced in the transition from the expanded schematic at the end of Section 2 to the historical mechanism. This reflects the fact that:

a) social housing was still in an experimental phase in its use of new reinforced concrete and cement systems, and this would only mature with the increased pressure from greater postwar societal demands;

b) the 1902 revision of the Paris street regulations appears to have had a questionable long-term influence on design and construction using the novel materials-system, and more broadly speaking the technical regulation of construction as we currently understand it had not yet developed fully by 1914.

The 'core' components of the historical mechanism (1a, 1b and 1c) have the most information within them sequentially linked in a flow process from left to right in the diagram. The first core component (1a) describes the process of converting a building commissioner's needs into key structural requirements, linked to the employment of novel reinforced concrete and cement systems in two typologies of *Belle Époque* urban buildings. Developed from the technical, societal and building design contexts described in the three sections, these key structural requirements included in this order: fire resistance, structural efficiency, daylight admission, street decor and social attributes. They were either more or less prominent in the two typologies described earlier in this chapter and are therefore ordered in terms of their overall significance across both typologies. The second core component (1b) of the flow process describes the application of early industrial standards for the novel materials-system to the key structural requirements; this included the key components of industrial patents, structural specifications and technical guidance, all described in Chapter 1. The flow process continues across to the final core component (1c). Hence the successful application of early industrial standards to key structural requirements would ensure a balanced use of technology and aesthetics in the building's final design composition; this assumed a coherent, novel materials-system was employed, and that there was adequate allowance for expressive freedoms and due acknowledgement of communal standards. The last two aspects of component 1c were considered within the sub-parts of Chapter 5 focused on *Belle Époque* Eclecticism and of Chapter 4 focused on the regulatory pressures on urban construction, particularly in Paris.

The subsidiary components of the historical mechanism (2a, 2b and 2c), which describe the professional attributes of design and build specialists, are *not* linked to each other by the same flow process connecting the three core components. However, there is a logical order to them. The first subsidiary component (2a) describes the professional confidence of specialists in the novel materials-system in their technical design abilities, which is governed by core component 1a about converting building commissioner needs into key structural requirements. The second subsidiary component (2b) describes the fact that these specialists needed to possess the right technical design and application skills, which is governed by core component 1b about applying early industrial standards to the key structural requirements. The final subsidiary component (2c) captures the fact that the completed build needed to reflect its design intentions, and is governed by subsidiary component 1c about balancing technology and aesthetics in the final design composition. The subsidiary components are derived initially from Chapter 4, which considered the role of technical design and build specialists, and raised an issue about the professionalisation of specialist contractors in the novel materials-system. This has been supplemented by discussion in Chapters 5 and 6 on what have become components 1c and 2c of the mechanism. All of this will be considered more fully in using the historical mechanism.

6d. Using the historical mechanism

Certain reinforced concrete and cement *Belle Époque* buildings which have neither been included in the case studies, nor have contributed to the definitions of the two typologies, have been recognised by leading researchers for their historical significance in the pre-development of the International Modernist architectural movement. This recognition has not centred solely on the technical design aspects of the buildings linked to the use of the novel material-system. One of these buildings will be used to show the historical mechanism in action. There are three candidate non-monumental, urban buildings proposed for this purpose, all private *immeubles* in Paris, and these are shown in Table 3.3 with the design and build specialists involved and their key design features. It should be noted that all of these are still with us and *none* of them employed the same reinforced and concrete systems featured in the historic buildings in the cases studies and resulting typologies. Of these three buildings, the private *immeuble* at 25b rue Benjamin Franklin in Paris by the Perret brothers and Latron & Vincent (Figure 3.20) stands out as *the* significant historical structure.

Table 3.3: Three potential Parisian buildings on which to use the historical mechanism

Building (Year Completed)	Specialists and systems used	Key design features
Immeuble, 25b rue Benjamin Franklin, Paris (1904)	Perret brothers, Latron & Vincent, adapted Coignet system.	Truly monolithic structure. Semi-octagonal *redan*, bay windows and roof-terrace. Geometric- and organic-patterned tiling on the street facade makes structure visible, glass bricks to the rear reduces courtyard requirements.
Immeuble, 26-8 rue Vavin, Paris (1913)	Sauvage & Sarazin, Lecoeur, Piketty system.	Set-back terracing (*maison à gradins*), blue and white monolithic-effect tiling on the street facade.
Immeuble, 124-6 rue de Provence, Paris (1913)	Sauvage & Sarazin, Lecoeur, Piketty system.	Early Art Deco features on street facade, bay windows and internal mushroom pillars.

Figure 3.20: The unique u-shaped street facade of the immeuble at 25b rue Benjamin Franklin, Paris (Perret brothers, 1904). (Nick von Behr)

This is a still extant, non-monumental, urban building which has been thoroughly commented upon by other researchers; however, it was completed in 1904, almost a decade before the other two buildings were finished in 1913. The *immeubles* at 26-8 rue Vavin and 124-6 rue de Provence (see Figures 3.21 (a) and (b)) were both designed by the well-known architectural partnership of Henri Sauvage and Charles Sarazin, with technical design and build input from the engineer and inventor Pierre Lecoeur using the Piketty reinforced concrete system.[395]

Figures 3.21 (a) and (b): Modern views of the facades of the immeubles at 26-8 rue Vavin (left) and 124-6 rue de Provence (right), both completed in Paris in 1913, designed by Sauvage and Sarazin using the Piketty system. (both Nick von Behr)

Both buildings very much tied to later works by Henri Sauvage in the French capital: the *immeuble* at rue de Provence is connected to the extension to the *La Samaritaine Magasin 2* (1925-8, see Chapter 5), a pivotal example of the interwar Art Deco architectural genre that superseded *Art Nouveau*; and the *immeuble* at rue Vavin is linked to a later *immeuble* at 13 rue des Amiraux completed in 1930, which applied more fully the initial *maison à gradins* approach described in Chapter 1.[396] If a single one of the three buildings had to be selected for its historical significance, then it would certainly be the *immeuble* at 25b rue Benjamin Franklin; it

[395] Minnaert, *Henri Sauvage*, 92–93; Minnaert, *Henri Sauvage Ou l'exercise Du Renouvellement*, 227–29.
[396] Minnaert, *Henri Sauvage*, 93–95.

has become a standard reference for innovative historic urban building design and construction employing a novel materials-system, certainly in France, arguably within the wider geography of Europe and perhaps even further afield.

The technical design process

When examining how the novel materials-system was used for the *immeuble* at 25b rue Benjamin Franklin, Collins tells us that he had been informed personally by Claude Perret, the youngest of the three brothers, that the specialist contractors Latron & Vincent were employed for the reinforced concrete structure.[397] These gentlemen had previously worked with Edmond Coignet using his *ciment armé* system, but had then set up independently; the *immeuble* at 25b rue Benjamin Franklin was their seventh and largest project to date at a value of 40,000 francs – an ideal opportunity for them as recently-established specialist contractors, but also an indication that the Perret brothers wanted to make their mark with the novel materials-system. One assumes in both these cases, they deliberately choosing to decline the opportunity of technical advice from an established inventor such as Coignet or Hennebique, though Armand Considère subsequently sought from Auguste Perret references for the employment of Latron & Vincent as contractors – in fact they would also work for the Perret brothers on a separate Parisian building completed in 1904.[398] The Perret enterprise files held at the CAAC in Paris include engineering designs by Latron & Vincent (AP 535 52/1-14), of which one shown in Figure 3.22 clearly indicates that a *ciment armé* system was employed for the pillar-beam-slab design in a part of the floor, using what appear to be generic features of the novel materials-system at the start of the twentieth century.

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[397] Collins, *Concrete. The Vision of a New Architecture*, 181 fn14.
[398] “When Latron & Vincent executed for the Perret brothers the reinforced cement work of 25b rue Franklin in 1903-1904, as well as the floors of the building at the corner of avenue Niel and rue Rennequin 5°5, they had only six medium-sized projects behind them. The 'house in reinforced concrete sections' at rue Franklin was at the time their largest undertaking (worth 40,000 francs).” « Lorsque Latron et Vincent exécutent pour les frères Perret le gros-oeuvre en ciment armé du 25 bis, rue Franklin en 1903-1904 ainsi que les planchers de l'immeuble à l'angle de l'avenue Niel et de la rue Rennequin 5°5, ils n'ont derrière eux que six opérations de moyenne importance à faire valoir. La ‘maison en pans de béton armé’, rue Franklin, constitue alors leur plus grosse entreprise (40000 francs) » Delhumeau, *L’invention Du Béton Armé : Hennebique, 1890-1914*, 299–300, fns 505 & 506.

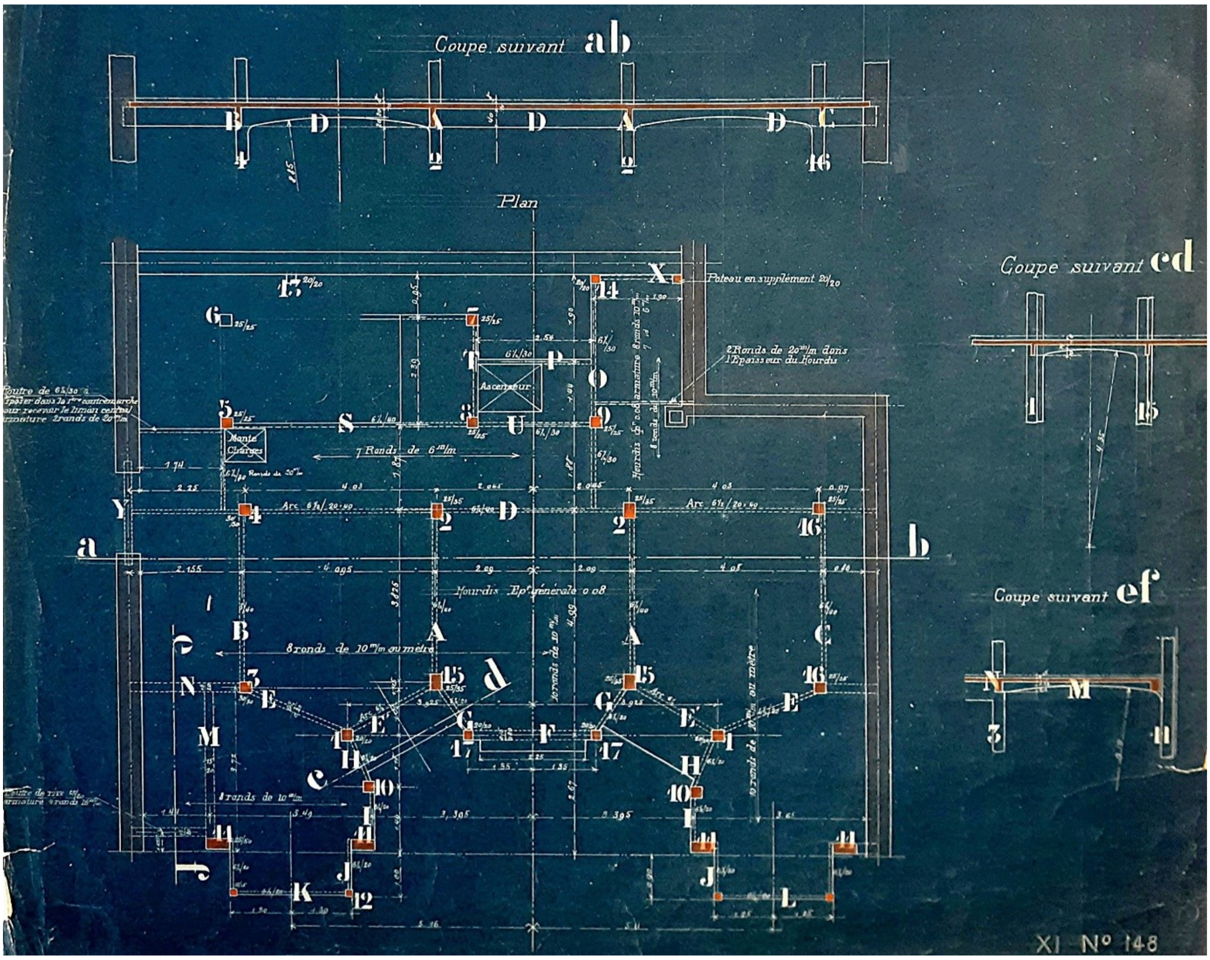

Figure 3.22: Latron & Vincent original structural plan of a floor showing column placement and a section of the ciment armé pillar-beam-slab system, for the immeuble at 25b rue Benjamin Franklin, Paris (Perret brothers, 1903). (535 AP 52/2. CNAM/SIAF/Cité de l'architecture et du patrimoine/Archives d'architecture contemporaine)

In terms of the role of technical design specialists, much of this for the *immeuble* at 25b rue Benjamin Franklin centred on the key personal attributes of Auguste Perret as the most significant of the three brothers. Abram examined the eldest Perret brother's overall architectural legacy in a detailed research report[399] and then wrote about the nature of the Perret father and brothers' organisation, covering a much broader time-period than the chronological span of this doctoral thesis, which finishes in 1914:

> Dalloz insisted on the close relationship between architect, engineer and contractor in an organisation where only projects detailed to the last door knob resulted, which of course considerably facilitated site work. The contractor never outpaced the architect, because in the 'ordered world' of the Perret firm, such a pretension would have been inconceivable … In its first years the Perret brothers' business was transformed from a general firm building traditionally to an new organisation using reinforced concrete

[399] Abram, 'Perret et l'école Du Classicisme Structurel (1910-1960)'.

> for architectural purposes, in order to realise a rationalist ideal formulated in the last quarter of the nineteenth century.[400]

Abram subsequently expanded on the organisation's 'rationalist' repertoire during the period leading up to and including the completion of the *immeuble* at 25b rue Benjamin Franklin, focusing principally on Auguste Perret as he done in his original research report.[401] The important context was that the lead design team of Auguste and Gustave could only really step out from under the shadow of their more traditional contractor-father, Claude-Marie, when the latter became ill and eventually died in 1905; at which point they combined with their younger brother Claude to ensure the administrative side of the building business functioned smoothly — much as Paul Sarazin had done for his architect brother Charles and his design partner Henri Sauvage. Since the brothers, indeed their family business, did not possess the technical knowledge needed for the employment of a reinforced concrete or cement system, they were forced to seek this externally, ultimately from Latron & Vincent as their sub-contractors. Bressani suggested that the Perret's bank may have hesitated in signing off the financing, because Latron & Vincent were relatively unknown at that time compared to more established reinforced concrete specialist contractors; however, he believed that Perret's design approach would not have been considered that unusual or risky for the time – this assessment has not changed since Bressani originally made it almost forty years ago.[402] Perhaps an unsuccessful rival firm may have had a hand in advising the bank to decline the risk, as a form of retribution for loss of business. We may never know.

The core components of the historical mechanism (1a, 1b and 1c in Figure 3.21) together capture a technical building design flow process, and this would appear therefore be relevant to the story of the construction of the *immeuble* at 25b rue Benjamin Franklin. Taking core component 1a, which is focused on converting building commissioner needs into key structural requirements, the *immeuble* was built on a restricted but highly sought-after plot owned by Claude-Marie Perret, as the building commissioner, head of the family and father of Auguste, Gustave and Claude. A suitable apartment in the building was intended for Perret senior's

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[400] Joseph Abram, 'An Unusual Organisation of Production: The Building Firm of the Perret Brothers, 1897-1954', *Construction History* 3 (1987): 75, 90.
[401] Abram, *Auguste Perret*, 22–27.
[402] Martin Bressani, 'Rationalism and the Organic Analogy in Fin-de-Siecle Paris: Auguste Perret and the Building at 25b Rue Franklin' (MIT, 1985), 67.

retirement and the sale or lease of other apartments was needed to help finance the venture no doubt; his wife continued to live in their apartment after his death in 1905, and Auguste would eventually move into another apartment in a roof extension to the top of the building.[403] It is not clear how highly valued the fire resistance of the building might have been (one assumes the bankers had not highlighted this as a risk), but clearly there were advantages in using a derivation of Coignet's *ciment armé* system to protect both family inhabitants and the physical contents of the new family business offices, not least contracts and drawings if not also financial artefacts. Those business offices were moved into a specially designed space on the ground floor; and there was a key building commissioner need, converted into a structural requirement, for the whole building to be both structurally efficient and truly monolithic, as described in Chapter 2. In terms of the other key structural requirements in component 1a of the historical mechanism, it would have been useful to admit as much daylight as possible into the interior for the business's employees and other occupants. It was for this reason that in addition to the usual fenestration and a novel approach to the u-shaped street facade, which gave the appearance of a reversed back courtyard, the Perrets also employed semi-transparent glass bricks for the actual rear wall of the building; this lit up the main staircase to be found on that side, compensating for the limited space for a courtyard at the back. Street decor, in the form of a mix of organic- and geometric-patterned ceramic tiles designed by Alexandre Bigot, would definitely have been a structural requirement for the Perret brothers, whether or not the need originated from their father:

> Later in his career, [Auguste] Perret claimed that the only reason he covered the concrete with tiles was that he doubted that concrete was capable of protecting the steel reinforcement adequately. In 1904, however, he had given another explanation … Perret thus shared with his contemporaries the opinion that tile was a "natural" outer shell for concrete. For him, however, following Viollet's precept, it acted more as a skin which softened and corrected the coarseness of the core structure, expressing, nonetheless, its general configuration. It was analogous to the decorative system used by Orientals and described by Viollet.[404]

[403] Bressani, 58–59, 73–74.
[404] Bressani, 193–94. Bressani was referring here to Lecture XV in Volume 2 of Viollet-le-Duc's *Entretiens*. The French architect had praised the sixteenth-century Persian approach to the use of ceramic tiling both inside and outside their mosques as an integral component of the overall structure. Viollet-le-Duc, *Lectures on Architecture. Volume 2*, 196–98.

There were subsequent issues about the quality of the building's overall finish reflected in the degradation of the ceramic tile cladding used on the street facade, but these could be said to be minor in comparison with the whole structure that is still with us more than a century later.

If the building had been an HBM, then structural requirements for social housing would also have been converted from any building commissioner needs. It is always possible that some of these were relevant, reflecting Ford's argument explained in Chapter 3 about the transmission of improving hygiene standards between social housing and (luxury) private accommodation, particularly after the First World War. Core component 1b of the historical mechanism applies industrial patents, structural specifications and technical guidance for the novel materials-system to the structural requirements for the *immeuble* at 25b rue Benjamin Franklin. It was not a competitively procured building, so the importance of structural specifications was less obvious; however, one assumes that the Perret brothers' sub-contract with Latron & Vincent for the construction of the building's skeleton *was* informed by structural specifications, even though there is nothing in writing to add to the structural drawings that exist in the CAAC archives. The relevance of national technical guidance was less important at this time as the French Government only published the final recommendations of its Commission on the novel materials-system in 1906; and these would only apply to state-commissioned construction projects. Technical guidance does however connect to the role of industrial patents, more precisely for Edmond Coignet's *ciment armé* system, in the absence of full evidence on the adapted system used by Latron & Vincent. The Coignet system is described in Chapter 2 using an extract from Paul Christophe's technical guide to the novel materials-system, published just before work started on the *immeuble* at 25b rue Benjamin Franklin. It is possible that the Perret brothers and Latron & Vincent had read this key publication, with its many examples of how the various novel reinforced concrete and cement systems were employed in France and Belgium. They might well have been aware of other similar technical guidance.

The final core component (1c) of the technical building design flow process in the historical mechanism is described as balancing the use of technology and aesthetics in the building's final design composition. This was influenced through employing a coherent, novel materials-system, allowing expressive freedoms to operate while acknowledging communal standards sufficiently. The *immeuble* at 25b rue Benjamin Franklin certainly indicated a thoughtful *balance* between technology and aesthetics; even though it was the Perret brothers' first attempt at non-monumental, urban building design using the novel materials-system, and with supplementary technical assistance from Latron & Vincent. Le Corbusier had worked in the *immeuble* at 25b rue Benjamin Franklin for a year as a trainee architect in the Perret brothers' design studio and was clearly so impressed by their use of a novel reinforced cement system for the monolithic structural skeleton, onto which was then imprinted a highly creative overall design for the building, that he promoted it to others subsequently as the future of modern architecture[405]. Many years later, a young Martin Bressani explained in his 1985 Masters thesis why he had focused entirely on this single example of Auguste Perret's lifetime works, in a case study about rationalist architecture and organic theory in *fin-de-siècle* Paris:

> Generally speaking, the work of an architect must be understood as a series of experiments linked together. A global survey of an architect's career, however, may overlook the possibility of drastic reorientation or simply the abandonment of early hypothesis. The 25b is the perfect example of such occurrence.[406]

Abram, probably *the* expert on the Perrets, saw the building as a pivotal change of direction employing a novel materials-system and an accompanying innovative technical design approach after weighing up the opportunities this presented. While the small size of the plot bought by their father had made massive masonry construction difficult, it did not prevent them from erecting the same metal building framing they had used at the Faubourg Poissonnière, another Parisian *immeuble* completed by the firm in 1897. According to Abram, they studied both technical options but decided in favour of concrete.[407]

Of interest is a possible connection between the *immeuble* at 25b rue Benjamin Franklin and both the Urban Housing and Urban Industrial typologies that have fed in to the production of the historical mechanism. On the face of it, the building would seem to fit the Urban Housing typology best; hence earlier in this chapter when the two typologies were compared and contrasted, it was noted then with specific reference to this typology that the building was a more satisfactory expression of creative design using the novel materials-system than the *immeuble* at 1 rue Danton completed four years before (an example of the Urban Housing typology taken from the case study in Chapter 4). The rue Danton building certainly was an enormous design challenge for its

[405] For more on Le Corbusier's early years and key relationship with Auguste Perret see Paul Turner, 'The Education of Le Corbusier. A Study of the Development of Le Corbusier's Thought, 1900-1920' (Harvard University, 1971).
[406] Bressani, 'Rationalism and the Organic Analogy in Fin-de-Siecle Paris: Auguste Perret and the Building at 25b Rue Franklin', 26–27.
[407] Abram, *Auguste Perret*, 27.

relatively inexperienced architect, Édouard Arnaud; according to Belli-Riz, it would have required an architect-contractor like Auguste Perret to apply the novel materials-system in a new approach to urban housing architecture, as expressed by him a few years later in the *immeuble* at 25b rue Benjamin Franklin:

> But transposing these conceptions into the field of the apartment house in a central district of Paris was unimaginable before 1900. His generation was not ready for this challenge... One could almost say: Arnaud dreamed it, Perret did it.[408]

But, and with reference to the Urban Industrial typology, Bressani had originally argued that the Franklin building should in fact have been considered a direct derivation from industrial architecture:

> Perret boldly asserts the industrial presence into the midst of the elegant quarter of Passy where, until then, only a few carefully crafted buildings of *Art Nouveau* artists had disrupted the calm elegance of older houses … The "industrialism" of the 25b supported its rationalism; it even proclaimed it.[409]

Cusack had suggested prior to Bressani's bold pronouncement, that Auguste Perret may have seen monolithic British industrial warehouses in Newcastle completed in 1902 using the *béton armé* system, though she was careful not to assume any direct influence on the later *immeuble*.[410] Auguste could just as easily have seen the Charles Six wool-combing mill in Tourcoing, much closer to Paris (described in the case study on 'daylight factories' in Chapter 2), or similar forms of manufacturing facility. He may have even been inspired by the published designs for the Ingalls Building in Cincinnati, the world's first reinforced concrete skyscraper completed in 1903.[411] Belli-Riz has perhaps more reasonably advocated that the *immeuble* at 1 rue Danton, constructed using the *béton armé* system like the Six building, also had industrial design features to it.

In terms of due acknowledgement of communal standards, this feature of core component 1c of the historical mechanism clearly could have interconnected at the *immeuble* at 25b rue Benjamin Franklin. The building was designed and constructed just as the revised 1902 Parisian street regulations were coming into play. Chapter 4

[408] Belli-Riz, 'Le Béton Armé à La Recherche d'un Style', 647–48. « Mais transposer ces conceptions dans le domaine de la maison de rapport dans un quartier central de Paris, était inimaginable avant 1900. Sa génération n'était pas prête a relever ce défi … On pourrait presque dire: Arnaud l'a rêvé, Perret l'a fait ... »
[409] Bressani, 'Rationalism and the Organic Analogy in Fin-de-Siecle Paris: Auguste Perret and the Building at 25b Rue Franklin', 196–97.
[410] Cusack, 'François Hennebique: The Specialist Organisation and the Success of Ferro-Concrete: 1892-1909', 79.
[411] Condit, 'The First Reinforced-Concrete Skyscraper: The Ingalls Building in Cincinnati and Its Place in Structural History'.

examined the influence of this relaxation of the post-Haussmannian conforming regime in Paris, which is assumed to have permitted the flourishing of the *Art Nouveau* architectural genre of Eclecticism. The conclusion was that the transition point was not as significant as has been thought, certainly in terms of the influence of innovative reinforced concrete and cement systems on *Belle Époque* building design. Chapter 5 examined this further when looking at *Belle Époque* Eclecticism more generally, which in turn related to the greater creative design freedoms sought by French architects of the period, especially proponents of the *Art Nouveau* genre.

The professional attributes of 'sibling' specialists

The subsidiary components of the historical mechanism connect to aspects of the core components just described for the *immeuble* at 25b rue Benjamin Franklin. In effect, the core components 1a-1b-1c of the technical building design flow process govern respective subsidiary components of the historical mechanism, 2a-2b-2c. The subsidiary components describe the professional attributes of technical design and build specialists in the novel materials-system; these contributed to the sound quality and coherence of structural composition that took place, which is a key part of core component 1c. The professional attributes were: (2a) professional confidence in a specialist's technical design abilities; (2b) specialist technical design and application skills; and (2c) ensuring the completed build reflected the original design intentions. It is therefore helpful to employ these subsidiary components when describing the construction process for the *immeuble* at 25b rue Benjamin Franklin.

Chapter 4 already singled out the Perret brothers as an example of how, with the emergence of the novel materials-system and associated levels of specialist technical expertise, the design and build 'sibling' professional roles of architect, engineer and contractor started to converge away from a focus on rivalry towards one on both rivalry *and* cooperation. The expanding employment of reinforced concrete and cement systems for new non-monumental, urban buildings gave specialist contractors a technical 'foot in the door', from which they could then leverage a wider clientele in their principal localities and even further afield. Summarised in subsidiary component 2a of the historical mechanism, the Perret brothers and their specialist contractors Latron & Vincent acquired a growing professional confidence in their technical abilities to employ the new materials-system; this had been confirmed in the recognition of specialist contractors' roles as local agents for François Hennebique and other inventors of novel reinforced concrete and cement systems, such as

Edmond Coignet in the case of Latron & Vincent. Through their professional confidence they and the Perret brothers acquired independent technical design and application skills, summarised in subsidiary component 2b; this was beyond simply using without question the industrial patents and technical guidance provided to them, whether this was backed or not by prior example buildings or written or drawn structural specifications.

The suggestion was made in Chapter 4 that there may be a reasonable case for stating even more clearly than before that early reinforced concrete and cement systems contractors developed their own specialist professional status. From the perspective of the *immeuble* at 25b rue Benjamin Franklin, Auguste Perret had extreme professional confidence in his abilities, as well as exceptional building design skills – his education and career path, as detailed by Abram, Britton and Bressani and referenced in Chapter 4, provide ample proof of this, even though it did not necessarily connect to the possession of professional confidence and skills in *technical* design using the novel materials-system. This may have happened as Auguste and Gustave, in a real example of sibling cooperation, learned through the careful observation of the work of Latron & Vincent on the skeleton of the *immeuble* at 25b rue Benjamin Franklin, just as other French and Belgian building designers and constructors specialising in the novel materials-system had done before them. We do not know definitively, but the brothers would have probably read about at least some of the original industrial patents, as well as Christophe's technical guide and other similar works, studying within them the key novel systems and their details illustrated – this would confirm the connection between subsidiary component 2b and its governing core component 1b in the historical mechanism. Britton provided some helpful speculation from her analysis of Auguste Perret's contribution to French structural rationalist architecture – she noted the division of labour that was strictly observed in the organisation, where Auguste would make most creative design decisions, while Gustave would manage the engineering and constructional aspects, and Claude the business affairs:

> Perhaps the dominance of Auguste among the three brothers despite their division of labor is due in part to his self-conscious development of a role, both personally and professionally, which in turn made him the visible and obvious candidate to fulfill the "post" expected of an innovator within the tradition of structural rationalism.[412]

[412] Britton, 'Auguste Perret', 250.

This is where the nearby *immeuble* at 9 rue Claude-Chahu, completed slightly earlier, comes into play as an historic example building described in the case study in Chapter 5 of two Parisian private *immeubles* with decorative ceramic facade cladding, and which are included within the Urban Housing typology. Collins was keen to make the connection between the design and construction of the *immeubles* at 25b rue Benjamin Franklin and 9 rue Claude-Chahu, both completed during the period 1903-4 and located a few hundred metres apart in the same outlying and expanding Parisian suburb of Passy. As a reminder, the analysis of the *immeuble* at 9 rue Claude-Chahu in the case study supplemented Legault's and then Gillet's doctoral theses, focusing on its unique decorative street facade in which Eric Muller's stoneware cladding was integrated, and which hid behind it a monolithic skeleton constructed using Hennebique's *béton armé* system. The *immeuble* at 25b rue Benjamin Franklin faced similar limitations. These included the small size and awkward shape of the plot, as well as the fact that the relatively inexperienced architect for *immeuble* at 9 rue Claude-Chahu, Charles Klein, was the son of the building commissioner, though in his case his father was an established architect rather than an experienced building contractor as was Perret *père*. Charles Klein may not have had the same professional confidence in his technical design skills as his architectural contemporary, the brilliant young Auguste Perret; the latter also had additional building design advantages over Klein, including the specialist support of his architect-engineer brother Gustave, and the collective construction experience gained from a successful family contracting business over many decades.[413]

The question remains as to whether Auguste, and Gustave, boosted their existing professional confidence and specialist skills by reflecting on the *immeuble* at 9 rue Claude-Chahu, in either a positive or negative sense, as Collins initially maintained and others have subsequently supported. Bressani indeed subsequently suggested that the earlier Klein *immeuble* might have served as a counter example to the Perret brothers – he maintained that the rue Benjamin Franklin building had respected the traditional distribution of the *maison à*

[413] A similar analogy applies to the early twentieth-century architect-engineer team of German-born siblings Albert and Julius Kahn. They operated in North America designing and building 'daylight factories' (see the case study in Chapter 2) and other industrial and commercial buildings using the novel materials-system, and later independently of each other, and further afield. Albert's first practice partner was Ernest Wilby from Harrogate, England, to whom Hildebrand gives credit for bringing the technical design legacy of early Yorkshire textile factories to the partnership. See: Hildebrand, *Designing for Industry. The Architecture of Albert Kahn.*; Hyde, 'Assembly-Line Architecture: Albert Kahn and the Evolution of the U.S. Auto Factory, 1905-1940'; Bucci, *Albert Kahn: Architect of Ford*.

loyer, which was the best proof of Perret's disregard for typological issues, such that his goal became one of renewing architecture rather than creating a new architectural or building typology:

> A glance at both exteriors immediately reveals that apart from their use of similar materials, the two buildings are profoundly different. Even if Klein has used so called "progressive" materials, he has reaffirmed the nineteenth-century type of the *maison à loyer* and has stayed within the established code.[414]

It should be noted that Bressani's use of the word 'code' is variable throughout his Masters thesis, ranging from precise Parisian building regulations to an architectural doctrine or canon, but in this particular extract he clearly means the latter. More generally, Bressani's commentary exemplifies issues about the normalisation of *Belle Époque* professional approaches to using the novel materials-system, and how emerging design and build specialists were caught between conservatism and radicalism in their technical design and construction of buildings, notwithstanding any conforming regulatory pressures that may have applied to their projects.

Returning to the 'sibling rivalry and cooperation' narrative of the converging professions of architect, engineer and contractor, as adapted from Saint in relation to the use of the novel materials-system; the manner in which the three Perret brothers operated, gradually specialising in the employment of a reinforced concrete and cement system, was an indicator of how a traditional urban building construction business could help develop a new community of shared *technical* design and practice in response to significant technical change in the industry – this also connects back to Addis's original model of the 'Design Procedure' and its application in a 'Design Revolution' (see the Historiographic Framework). Was Henri Sauvage of a similar technical design calibre as Auguste Perret, even though not working in a partnership that derived its principal income from delivering contracting projects? How many specialist contracting businesses that employed the novel materials-system became specialist technical *designers* in reinforced concrete and cement systems? Where do we place within this spectrum of professional competence the original inventors of the novel reinforced concrete and cement systems and their central design studio personnel and affiliates? We know that some of Hennebique's agents and *concessionnaires* were highly trained and skilled civil and structural engineers. All of such factors would need to be considered when using the historical mechanism with other candidate historic

414 Bressani, 'Rationalism and the Organic Analogy in Fin-de-Siecle Paris: Auguste Perret and the Building at 25b Rue Franklin', 195.

non-monumental, urban buildings that employed the novel materials-system. Slaton in America, Deuten in Europe, Van de Voorde, Degraeve and colleagues, and Bulckaen and Devos in Belgium, and Melsens in India, have all examined professional and contracting issues in more detail, often with specific reference to the use of novel reinforced concrete and cement systems in the twentieth century. One aspect of professional attributes related to the role of intermediaries, specifically component 2c of the historical mechanism, will be explored next.

The role of intermediaries in historic construction

Subsidiary component 2c of the historical mechanism underlines the importance of specialists ensuring that the final build reflected the original design intentions. Related to this notion, in the historiographic review and Chapter 4 the issue was first raised that some of the actors involved with building design and construction using the novel materials-system might have played the role of an intermediary. Architects, engineers and contractors all belonged to the same category of actor, sharing objectives of wanting to deliver construction projects successfully for their clients; but with different perspectives on the risks involved.[415] Architects might have seen these risks from the perspective of their creative reputation, whereas engineers may have felt a professional obligation to design a structure that met minimum physical standards, not least of which was structural efficiency and resilience over time. The risk shared by both of these types of building design actor was to convert commissioner needs satisfactorily into key structural requirements connected to the employment of a novel materials-system; with all of this resulting in a balance between the technological and aesthetic aspects of a buildings' design composition. Contractors, by contrast, were required to deliver a completed construction project for a new build that fitted the combined needs and design intentions of the building commissioner, architect and engineer (if one was employed as an additional source of technical advice). It would have been in a contractor's best interests to mitigate risks in completing the building project

[415] For more research on this interesting topic, that also builds on Saint's concept of 'sibling rivalry', see academic papers by Bulckaen and Devos which examine the key issues from a Belgian perspective and reference the use of reinforced concrete systems: Laurens Bulckaen and Rika Devos, 'The Engineer as Mediator in Complex Architectural Projects at the Turn of the Nineteenth Century: The Case Study of Louis Cloquet', in *Construction History Society Conference Paper*, 2020, 405–18; Laurens Bulckaen and Rika Devos, 'The Ghent Booktower (1933–1947): A Product of Collaborating Professionals within Institutional Know-How', in *History of Construction Cultures - Proceedings of the 7th International Congress on Construction History, 7ICCH 2021*, vol. 1 (CRC Press/Balkema, 2022), 538–45, https://doi.org/10.1201/9781003173359-70; Rika Devos and Laurens Bulckaen, 'Collaboration in Historical Buildings: Self-Evident but Intangible', in *Construction Matters* (8th International Congress on Construction History, Zurich: vdf Hochschulverlag AG, 2024), 463–70.

to the satisfaction of their clients and being so paid in full without future obligations, assuming they were fully aware of competing demands from the other actors for what each deemed to be a successful outcome. In delivering the final building, contractors needed to be able to distinguish, and if need be reconcile, contrasting technical design views in order to finish the project with minimal delay, as a close as possible to the agreed final design and cost and with any justifiable allowances fully accounted for. A contractor's reputation for completing projects might have been enhanced by a design that easily satisfied prevailing societal tastes; but they would not have been paid unless at least the building commissioner and the architect considered the finished building to have met their contractual requirements – hence why Charles Six became so embroiled with his contractor Debosque-Bonte, and through him with François Hennebique, perhaps even with his unknown architect, in what he perceived to be the unsatisfactory delivery of his new wool-combing mill in Tourcoing; this even though the finished building was subsequently admired by others (see the case study of 'daylight factories' in Chapter 2). A few years later in Paris, the interesting part of the Perret brothers' design solution to the structural requirements of the *immeuble* at 25b rue Benjamin Franklin, was their desire to innovate *within*, rather than *without*, any constraints set by their commissioner parent, the restricted plot size and shape and any Parisian street regulations that (they perceived) applied to the outer suburb of Passy, probably in that order of importance to them. They might not have been able to do this without their family's prior contracting experience, as well as the specialist knowledge that Latron & Vincent had acquired in their adapted Coignet *ciment armé* system used to construct the building's skeleton. This was a risk-mitigating process that gave them the required professional confidence (component 2a of the historical mechanism) and skills (component 2b of the historical mechanism) to employ an innovative approach to the overall design of the building.

The intermediary role was complex for contractors, just as the relationship between the professional attribute components and the rest of the historical mechanism is not a simple one. A further research project could drill down into the key aspects of risk associated with each component of the mechanism. This might lead to a better understanding of how the actors might actually have reflected the original design intentions in the completed structure through using a novel materials-system. We know of many historic instances of famous *monumental* urban buildings that have particularly struggled with this risk mediation process – the examples of the Sagrada Familia and the Sydney Opera House both come to mind, for which highly novel practical construction solutions had to be found to meet futuristic commissioner needs through resulting structural requirements. There was of course a trade-off between societal approbation and structural efficiency, particularly for non-monumental buildings where functional needs outweighed issues around form or decor. Such future research on construction risk could also connect to the broader historical issue of controlling the development of technology from the start of the world's First Industrial Revolution in the eighteenth century. Miriam Levin analysed this in the first chapter of a book of academic contributions for which she had overall editorial oversight.[416] She saw the nature of control developing from an initial French medieval context, where it was a double accounting technique (*contre-rolle*) designed to normalise administrative procedures and limit corruption, for the benefit of state coffers – so to some extent an early form of process standards as we currently know them. As Levin describes the term, control then expanded within the philosophical thinking of the Enlightenment, into a rationalist philosophy epitomised by Adam Smith's 'Wealth of Nations' and Diderot's *Encyclopedie*. Humans had the confidence and ability to control the means of production for themselves, not simply by the hand of God alone, and this particularly by using innovative machinery and production systems; why not therefore create greater value through more sophisticated assembly line processes?[417] Of course, it was still the wealthy who oversaw these new processes and the poor who laboured hard to operate them for their masters. This was a fact that Henry Ford had tried to gloss over when marketing the brand value of his vast 'daylight factory' near Detroit, built using Taylorist management methods that also applied to the hard-pressed labour force churning out thousands of standardised Model-T's.

Chapter summary

The chapter began by describing two typologies (Urban Industrial and Urban Housing) derived from twelve historic *Belle Époque* example buildings in the case studies, all of which employed the novel materials-system. The two typologies are the product of a filtering exercise that began with many potential historic example buildings whether still extant or not and connect well to the technical, societal and building design contexts and associated case studies described in the previous chapters. These historic factories, depositories of valuable items and urban buildings (designed primarily for block accommodation, whether rented out at market rates or subsidised by charitable organisations), were each and all the product of unique and shared

[416] Miriam Levin, 'Contexts of Control', in *Cultures of Control*, ed. Miriam Levin (Routledge, 2004).
[417] Levin, 21–24.

needs set by their building commissioners, shaped by the *Belle Époque* society in which they lived. This was influenced by a gradual shift of the existing paradigm of a 'normal' to a 'new' community of building design processes that constituted the two-stage metallic building design revolution described in the previous chapter – the first stage based on the use of iron and steel with or without protective cladding, the second increasingly based on the emerging reinforced concrete and cement systems. Previously somewhat neglected structures are included within the historic example buildings from which the typologies were derived, not least those 'daylight factories' in the Urban Industrial typology that were located near Lille and Paris; between them they also illustrate the early employment of the *béton armé* and *béton fretté* systems.

By comparing the common and differing key structural requirements in the Urban Industrial and Urban Housing typologies, a historical mechanism could be produced from the updated schematic at the end of Section 2, with its suggestion of a flow process connecting key information blocks. The purpose of the historical mechanism is to help explain through a model, the means by which the new reinforced concrete and cement systems influenced *Belle Époque* design of non-monumental, urban buildings. The core components of the historical mechanism contain five structural requirements converted from key building commissioner needs: fire resistance, structural efficiency, daylight admission, street decor and social attributes. Early industrial standards, in the form of industrial patents, structural specifications and technical guidance for the novel materials-system, could be applied to these structural requirements to ensure that the final structural composition of a building reflected adequately the balance between technology and aesthetics. This assumed a sufficient quality and coherent novel materials-system, certain freedoms in creative design and due acknowledgement of communal standards, the latter expressed at the time through municipal street regulations. These core components of the historical mechanism each govern a set of subsidiary components that described the required professional attributes of the specialist architects, engineers and contractors who used the novel materials-system.

The historical mechanism was then used with the *immeuble* at 25b rue Benjamin Franklin in Paris, a well-researched, non-monumental, urban building completed by the ground-breaking Perret brothers in 1904. The mechanism appeared to function for this building, by providing a useful causal framework for analysis of its technical design and aesthetic features, and the relationship between the two facets. The conversion of specific building commissioner needs into key structural requirements may of course vary according to the different typology or individual example of historic building to which the historical mechanism is applied. The subsidiary components of the historical mechanism helped to explore two related propositions about the attributes of specialists in the new reinforced concrete and cement systems of the *Belle Époque*: the first referenced the increasing professionalisation of specialist contractors, while the second considered the extent and nature of intermediary roles for construction professionals using the novel materials-system. The 'rival *and* cooperative professional sibling' historical narrative adapted from Saint is a useful part of the model, but it needs to take greater account of the intermediary role that specialist contractors, in particular, were forced to embrace in order to mitigate the greater risks involved in building design and execution using new technical approaches. They needed to possess sufficient confidence in their abilities and specialist construction skills to ensure that the final build reflected the original design intentions. The chapter ended by examining the control of developing technology, as humanity's technical confidence grew from the eighteenth century onwards, permitting us to master industrial innovation and our natural environment.

Section 3 summary

Section 3 provided *Belle Époque* building design context and described a historical mechanism for the technical building design process using the novel materials-system, which was derived from the key information blocks and details in the updated schematic at the end of the previous section.

Chapter 5 covered two stages of a fifty-year metallic building design revolution (1864-1914), with particular focus on the second stage from 1892-1914. The first stage began with nineteenth-century monumental metallic building design that had initially used iron and the steel framing. The chapter then examined the predominant rationale for eclectic architecture during the *Belle Époque*, connected as it was to a highly decorative *Art Nouveau* architectural genre that first flourished in Brussels from 1893. The location and date coincided, as if by chance, with Hennebique's initial technical breakthrough for his *béton armé* reinforced concrete system. The chapter ended by considering non-monumental, urban building design connected to the novel materials-system, with two case studies of historic example buildings, the first on the use of decorative ceramic facade cladding, the second illustrating a new urban design approach.

Chapter 6 defined two typologies (Urban Industrial and Urban Housing) derived from twelve of the historic example buildings in the case studies. These were all constructed employing the novel materials-system, though with shared and differing technical and aesthetic approaches. The two typologies were contrasted, contributing to the final production of a historical mechanism based on two sets of components. The core components describe a flow process for the technical design of *Belle Époque* buildings using the novel materials-system; they governed subsidiary components describing the professional attributes of technical design and build specialists. The historical mechanism is intended to help answer the core research question, and so is first applied to the design and construction of the *immeuble* at 25b rue Benjamin Franklin in Paris by the Perret brothers. This confirms the value of the historical mechanism in helping to determine the influence of new reinforced concrete and cement systems on *Belle Époque* non-monumental, urban building design. It was suggested that the professionalisation of specialist contractors and the nature of their role as intermediaries between architects and engineers could be explored in further research employing the historical mechanism. This would need to consider more generally a historical process for the control of construction technology, as well as connect to the vast North American ‘daylight factories’ typified by Henry Ford’s pre-First World War car-making assembly line near Detroit.

The subsidiary research question asked at the start of Section 3 was: ‘Which factors shaped *Belle Époque* urban building design and how did they interact with key technical demands and societal expectations for the novel materials-system?’ The description of the metallic design revolution (with its two stages) and the nature of Eclectic architecture and its radical *Art Nouveau* genre, together with the historical mechanism and its use on the *immeuble* at 25b rue Benjamin Franklin, all provide answers to this final subsidiary question. An answer to the core research question follows in the Conclusion to the thesis.

Conclusion

In this concluding part of the thesis, the three sections and their six chapters are first summarised; all of these structural elements of the thesis have contributed to the production of a historical mechanism as a key research outcome. The value of the historical mechanism in terms of helping to answer the core research question, and the value of its potential application to modern-day urban building design is then considered. This last appears to resonate with global priorities in an age where environmental sustainability has become critical, particularly in highly urbanised localities, as the world approaches possibly irretrievable deadlines for net-zero targets – which was of course far from the minds of *Belle Époque* building professionals and their commissioning clients. Then five subsidiary research outcomes are outlined, each with a separate assessment of their strengths and further research opportunities, and it is suggested that three of these research opportunities could be combined into a future research project. The conclusion ends with final summarising comments about the whole thesis, capturing the key elements within it that contribute to a growing knowledge base.

Summary of sections and chapters

Section 1 of the thesis provided details about the technical context of *Belle Époque* construction using the novel materials-system in two chapters, the first focused on early industrial standards with their three key components, the second on building economics and four key structural requirements. The section answered the subsidiary research question, 'What were the key technical demands of the new reinforced concrete and cement systems and how did these manifest themselves within building design and construction during the period?', by presenting two key information blocks and their associated details in a schematic diagram.

Section 2 of the thesis provided the societal context of *Belle Époque* construction using the novel materials system in two chapters, the first focused on hygienic cities and social housing, the second on construction actors, professionalism and regulation. The section answered the subsidiary research question, 'How did the employment of new reinforced concrete and cement systems reflect societal expectations and in what ways did these manifest themselves within building design and construction during the period?', by presenting two additional key information blocks of 'social housing' and 'professionalism' and their associated details in an updated and extended version of the schematic diagram in Section 1.

Section 3 of the thesis provided the context for *Belle Époque* building design and described a historical mechanism for the technical building design flow process using the novel materials-system. The section included two chapters, the first of which focused on the design of *Belle Époque* urban buildings using the novel materials-system, identifying two stages of a metallic building design revolution that spanned the fifty years from 1864 to 1914. The second chapter described two typologies (Urban Industrial and Urban Housing) that together contribute to the production of the historical mechanism. The core and subsidiary components of the mechanism were described and applied to the analysis of a final historic example building in Paris. This highlighted two related propositions about the attributes of, particularly, specialist contractors in the new reinforced concrete and cement systems of the *Belle Époque*: their increasing professionalisation and their assumption of a risk mediation role, with connections to the historical control of technology.

Section 3 answered the subsidiary research question, 'Which factors shaped *Belle Époque* urban building design and how did they interact with key technical demands and societal expectations for the novel materials-system?', by first describing these building design factors and then showing how the historical mechanism connected across all three technical, societal and building design contexts of the thesis; this confirmed the focus on a flow process for technical design and construction and how its components governed the professional attributes of confident and technically skilled specialists, particularly contractors, who were thus able to transform original designs satisfactorily into completed builds.

Answering the core research question

The rationale for producing and using a historical mechanism is to explain historical causation within the period and geography encompassed by this thesis and so help answer the core research question: 'What was the influence of novel reinforced concrete and cement systems on non-monumental, urban building design in and near three *Belle Époque* cities?'

While the historical mechanism did not in itself answer the core research question, using it on the ground-breaking *immeuble* at 25b rue Benjamin Franklin completed in Paris in 1904 by the Perret brothers, confirmed that the historical mechanism was helpful in simplifying the complex aspects of building design and construction; this from the perspective of both a technical flow process and associated professional attributes.

The focus of the core research question after the research and analysis has been completed can also be simplified to consider the **relationship** between two chains of historical events: A events (the emergence of a novel materials-system during the *Belle Époque*) and B events (the technical design and construction of non-monumental, urban buildings in and near Paris, Lille and Brussels between 1892 and 1914). In this way the range of key research parameters can be better focused in terms of whether historic example buildings of the period:

a) belonged to the Urban Industrial or the Urban Housing typology;
b) used the novel materials-system to meet differing aesthetic goals, whether or not these were creative design responses to the same or different technological factors;
c) were designed and constructed by different combinations of actors with more or less homogenous technical expertise.

There could be more parameters, in more detail; but the risk of an overly categorised approach, already highlighted in Chapter 6 in terms of typologies, would negate the benefits of simplification.

Acknowledging that uncomplicated answers can be helpful in explaining the relevance of the past, much as a single event in 1914 Sarajevo 'caused' a chain of subsequent events that led to a continent-wide war, how can this be applied to the thesis? Within Chain of Events A (the emergence of a novel materials-system during the *Belle Époque*), François Hennebique and other French inventors of new reinforced concrete and cement systems, including the highly respected civil engineer Armand Considère, came to the fore during the second stage of a metallic building design revolution between 1892 and 1914 – following a first stage of iron and steel. At the same time, within Chain of Events B (the technical design and construction of non-monumental, urban buildings in and near Paris, Lille and Brussels between 1892 and 1914) the novel materials-system that was emerging was welcomed by 'technically-gifted' architects who designed and indeed (self-)critiqued the specific historical examples used in the thesis. These architects included Édouard Arnaud, Anatole de Baudot, Louis-Charles Boileau, Auguste Bouvy, Henri Deneux, Léon Govaerts, Léonce Hainez, Ernest van Humbeek, Charles Klein, Auguste Labussière, Auguste Perret, Charles Sarazin, Henri Sauvage and Stephen Sauvestre. Only a design by Sauvestre appeared in the popular 1893 publication *Hôtels et mansions de Paris*, together with those of other well-known French architects of the late nineteenth century, none of whom are listed previously.

While not yet able to capture fully the technological impact of the second stage of the metallic building design revolution which had 'begun' in 1892, these *Belle Époque* non-monumental, urban buildings symbolised a high international regard for increasingly expressive, eclectic architecture in post-Haussmannian Paris; particularly so in North America, where a more decorative counterreaction to new functional skyscrapers in Chicago and New York was beginning to emerge.[418]

Equally, within Chain of Events A (the emergence of a novel materials-system during the *Belle Époque*), the second stage of the metallic building design revolution saw a growing number of engineers and contractors in addition to the above architects, improve their technical understanding of and skills in converting commissioner needs into key structural requirements, and in turn into designs and completed builds that used the novel materials-systems. At the same time, within Chain of Events B (the technical design and construction of non-monumental, urban buildings in and near Paris, Lille and Brussels between 1892 and 1914), there is evidence to show that two historic manufacturing premises completed near Paris and near Lille before 1914 fitted with an emerging transatlantic architectural typology of a 'daylight factory', and its broader ramifications for International Modernism after the First World War. There is also growing evidence of the adoption of the novel materials-system in the design and construction of new social and private housing, as well as commercial premises, with greater or lesser 'success' in terms of a sound balance between technology and aesthetics.

More broadly speaking, the legacy of structural rationalism as proselytised by Viollet-le-Duc and his disciples in the footsteps of intellectual predecessors such as Henri Labrouste, had been channelled into an *Art Nouveau* architectural genre **and** metallic design and construction outcomes, both under the umbrella of *Belle Époque* Eclecticism. Again, within Chain of Events A (the emergence of a novel materials-system during the *Belle Époque*), François Hennebique, to promote his rapidly expanding business, had transitioned Louis-Charles Boileau's vociferous counter-argument to structural rationalism into a new mission to embrace the (mono)lithic qualities of the novel materials-system. At the same time, within Chain of Events B (the technical design and construction of non-monumental, urban buildings in and near Paris, Lille and Brussels between

[418] Pierre Gelis-Didot, *Paris Mansions & Apartments 1893. Facades, Floor Plans & Architectural Details.* (Dover ed., 2011). See particularly pp. ix-x in the introduction by Christopher Drew Armstrong. Leslie's 2008 paper referenced in the case study of 'daylight factories' in Chapter 2, covers well the relationship between the technical and aesthetic building design drivers of developing Chicago skyscrapers, including their use of steel framing, plate glass and cladding, as well as responding changes in municipal building regulations.

1892 and 1914), the completion of the *immeuble* at 25b rue Benjamin Franklin in Paris in 1904 was the first clear signal, though not fully appreciated at the time, that significant change was occurring in *Belle Époque* non-monumental, urban housing. It would take a man of Auguste Perret's creative and technical talents, with the support of his experienced family contracting organisation, to bring this to fruition in his developing efforts with reinforced concrete on either side of the First World War – he would move into more monumental and hence memorable projects in and near Paris, including the *Théâtre des Champs Élysées* before the war and the Church of *Notre-Dame du Raincy* after it.

Relevance of the historical mechanism to modern-day urban building design

Is the historical mechanism described and used in this thesis, and the accompanying historical interplay of specialist construction professionals, relevant to a modern-day context for urban building design whether in France, Belgium or the rest of Europe? To some extent yes, but further research beyond the thesis is required to fully assess the significance of this.

When considering the modern-day relevance of the historical mechanism, it is important to include one of the major current complexities which had *no* relevance at all to *Belle Époque* building commissioners and construction professionals; this is ensuring that a better use of construction materials and a greater focus on sustainability in the design of urban buildings contributes to a shared global objective of reducing the human contribution towards an over-heating environment. One might have argued that this expansive and at times almost philosophical motivation simply replaced unpredictable, complex and unregulated warfare such as happened in nineteenth- and twentieth-century Europe; however such reasoning is clearly too hasty, and it would be safer to comment that there are many types of human-based and natural threat to, and caused by, our built environment.[419] A significant human-based threat that is still prevalent in the European built environment is a persisting demolition of existing buildings and associated urban infrastructure, for primarily economic or political reasons. Worse still, the replacement of these buildings uses what is now understood to be a highly carbon-intensive reinforced concrete materials-system, involving billions of tonnes of cement

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[419] For example, none of the three modern European metropolises of Paris, Lille Metropole and Brussels sit in an earthquake zone near a coast, so any threats from ground movement and resulting tidal waves remain to this day minimal – it could be noted that global construction techniques using novel materials-systems have not yet been forced to perform to the same technical standards as those employed in many seaboard metropolitan areas near major plate boundaries along the 'Ring of Fire' that surrounds the Pacific Ocean.

produced using high-energy kilns, as well as vast amounts of steel for reinforcing bars, all of which take a heavy environmental toll on our planet. On the positive side, there are efforts to mitigate against this negative impact. Hence, a modern-day project run by a multinational construction business is planning to reduce the carbon content of cementitious materials without compromising the structural properties of the materials-system in which they are employed.[420] The lessons from such approaches to improving the dominant materials-system could easily be applied by other enterprises and whole sectors of the construction industry to wider effect. This is because the current employment of reinforced concrete systems has a three-fold negative impact on the environment: the first in the production of the lithic materials, particularly cement; the second in the production of steel rebar; and the third in the building operations themselves, which involve machinery and transport vehicles powered by fossil fuels – a long-term solution may be to use Modern Methods of Construction (MMC) for urban house building.[421]

Early industrial standards are a historical concept within the broader and more familiar current meaning of technical standards: what we mean today by voluntary product, process and people-related standards overseen by (inter)national standards bodies established in the first quarter of the twentieth century, such as ISO, AFNOR or BSI. As described in this thesis, early industrial standards for the innovative reinforced concrete and cement systems employed in *Belle Époque* non-monumental, urban buildings consisted of three key components: industrial patents for the novel materials-system, structural specifications and technical guidance. Of these three components, technical guidance most connects to the modern building codes and planning, health and safety regulations that apply to contemporary design and construction; but the exact nature of this relationship depends on a range of extraneous factors, not least those deriving from the communal and cultural prerogatives of different periods and in different localities. These have become more complex as industrialisation and urbanisation have expanded since the time of the *Belle Époque*. So an immediate step would be to encourage controlled simplification of technical design approaches, for which the historical mechanism might provide a useful initial tool.

[420] Ana Pavlović, Glen Rust, and Harry Edwards, ‘Decarbonising Precast Concrete Manufacturing: Implementation of Low-Carbon Concretes’, in *Fib Symposium 2023*, ed. A. Ilki et al (Springer Nature Switzerland, 2023), 418–28.

[421] For more on MMC see: https://www.productivity.ac.uk/research/driving-change-in-uk-housing-construction-a-sisyphean-task/ (accessed 18/12//2023).

As already noted, the work of the many technical committees still used by (inter)national standards bodies is very much centred around interpreting process and product specifications, patents, technical guidance and regulations for wider industrial application. The UK national standards body (BSI) has therefore recently developed a freely downloadable fast-track standard PAS (440) to "help innovators achieve greater sustained impact, both economically and socially", as well as launching in April 2023 a revised fast-track standard PAS (2080)[422] on managing and reducing carbon in the built environment, with additional guidance sponsored by the Institution of Civil Engineers (ICE) and the Green Construction Board (GCB). Connected to these British fast-track standards, and specifically in terms of innovations that are now developed and patented within the globalised construction industry, much current research focus is on reducing the amount of carbon embodied in the manufacture and application of reinforced concrete and other materials-systems in order to meet 2050 net-zero targets. The guidance to the revised PAS (2080) published by ICE and GCB takes the form of a lengthy document with much contextual information for engineers and constructors, one part of a multi-layered professional construction project team – which connects well to the role of the key construction actors, and more specifically the professional attributes that are subsidiary components of the historical mechanism. The material/product developer in a construction supplier's role is advised in the guidance to establish "a process to engage with other designers, constructors and product/materials suppliers to keep up to date with innovation in the industry that will drive whole-life carbon reduction at asset, network and system levels".[423] The guidance identifies modern work stages in construction projects of which the 'Need', 'Optioneering', 'Design' and 'Delivery' stages connect to the core and subsidiary components of the historical mechanism described in this thesis. The modern 'Need' work stage is one where the client is helped to define the commissioning needs that would support net-zero transition. By contrast:

> The Optioneering stage provides opportunities to avoid carbon, switch to lower-carbon design approaches and improve material and performance specifications for lower carbon and resource efficiency.[424]

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[422] https://pages.bsigroup.com/l/35972/2020-03-17/2cgcnc1 and https://www.bsigroup.com/en-GB/standards/pas-2080/ (both accessed 9/6/2023)

[423] 'Guidance Document for PAS 2080 Practical Action and Examples to Accelerate the Decarbonisation of Buildings and Infrastructure' (Institution of Civil Engineers, April 2023), 23.

[424] 'Guidance Document for PAS 2080 Practical Action and Examples to Accelerate the Decarbonisation of Buildings and Infrastructure', 38.

It seems therefore that 'Optioneering' is a critical stage in the moderating process for urban building design, whereby a professional actor is able to mitigate the negative impact of any unknowns by trialling the conversion of building commissioner needs into structural requirements, importantly at lower levels of financial exposure – this could be applied not only to achieving net-zero targets but also to other objectives associated with a modern approach to design and build, not least MMC referenced earlier. The 'Optioneering' stage resonates with the concept of construction intermediaries elaborated under the use of the historical mechanism and linked to the role of specialist professional contractors in a novel materials-system. The 'Design' and 'Delivery' work stages in the guidance to the revised PAS (2080) offer further opportunities to influence the construction project, with specialist building designers and contractors both insisting on the use of low-carbon materials and considering end-of-life carbon during materials selection; also by specialist architects and engineers designing for disassembly and material re-use at end of life, as well as contractors embracing innovative construction techniques to minimise fuel use and optimise energy use. A section of the guidance outlines the key role of collaboration between all the key actors at both an institutional level and a project-based level, in order to collectively increase decarbonisation in construction – this collaboration is facilitated by the professional bodies that have emerged since the nineteenth century in the UK, France and elsewhere; indeed ICE, as one of these professional bodies in the UK, is the main sponsor of the revised PAS (2080) and the official publisher of the accompanying guidance. A design-based example in the guidance of such a collaborative project is one run by the Royal Institute for British Architects (RIBA) called the 2030 Climate Challenge, which started asking member architects in 2021 to reduce embodied carbon in their designed buildings by at least 40% from their then business-as-usual baseline figures, before offsetting, by 2030.[425]

Any further research derived from the historical mechanism of relevance to the modern era would therefore require consultation with current (and future) building designers, much as Angelino employed surveys and interviews to inform her research-based theory and practice in the application of international building standards (see Chapter 1). The inclusion of future building designers would be particularly interesting, as it would allow more radical 'outside the box' thinking which could be channelled appropriately by wise heads in

[425]See https://www.architecture.com/about/policy/climate-action/2030-climate-challenge (accessed 9/6/2023).

the form of students' academic staff and industrial mentors. Such further research would also need to cover all of the main pathways to the building professions, preferably via combined or integrated building design courses – this may well set the geographical remit of such a study. The final outcome of such a second stage of research could be a validated theory of change that could be used to inform future measures within the field of construction – more specifically, connected as closely as possible to commonly agreed net-zero targets.

Subsidiary research outcomes

There have also been five subsidiary research outcomes from the broader research project which are each described briefly below (they are listed in table 3.4 in the Appendices with their relative strengths and further research opportunities):

1. Adding to the state of knowledge about fourteen *Belle Époque* non-monumental, urban buildings which have had varying degrees of prior research focus, commentary and significance, and two of them are sadly no longer with us;
2. contributing to a broader debate about the historic role of innovative materials and systems for building design and construction, and novel combinations of these into what have been termed 'materials-systems'; all with specific reference to the early use of reinforced concrete and cement in structurally efficient and fire-resistant urban buildings;
3. re-assessing the origins of the North American 'daylight'/'rational' factory typology and its connections with the International Modernist architectural trope created by Le Corbusier and Gropius as described in this thesis. This was linked to early Northern French building commissioner needs, converted into structural requirements for more fire-resistant and structurally efficient manufacturing buildings that admitted more natural light into more spacious interiors. Early reinforced concrete and cement systems represented a novel materials-system that could provide a design solution to such key structural requirements;
4. examining further the relationship between historical societal and regulatory pressures for greater urban hygiene in order to combat highly contagious diseases, and the technical design of clean, urban accommodation that permitted affordable levels of rent for the poorer classes of *Belle Époque* society. There is a modern-day analogy here with the threat of global pandemics and increasing

pressure for more affordable and sustainable housing in a period of rising land values in expanding, densely-populated urban areas of the globe; and

5. endorsing further research on the technological-aesthetic influence of twentieth-century urban regulations on building design using reinforced concrete and cement systems *after* the First World War. Municipal regulations and codes of building practice e.g. Eurocodes have since became connected to pan-national technical standards during the course of the twentieth century down to the modern day, not just for building materials, systems, products and processes; but also with an increasing focus on an expanding global professionalisation of the construction industry, with improved rules for societally-responsible personal conduct.

Looking at further research opportunities, it might be appropriate to merge those for outcomes 2, 3 and 5 into a single research project that would examine comparatively the historic employment of reinforced concrete and cement systems in Europe/Britain and the United States over a specified period of time after the First World War. Such research could be centred around comparative case studies of 'daylight' and 'rational' factories and those other urban buildings most closely related to these two typologies (Urban Industrial in the case of this thesis); as well as the influence of maturing construction- and design-related regulations, codes of practice and technical guidance, and the changing role of specialist contractors as intermediaries for the employment of novel materials-systems in building design and execution.

Concluding comments

In addition to producing a historical mechanism that has helped answer the core research question and might also be applied to other historical and modern-day contexts, what contribution has this doctoral research made to the current state of knowledge about construction history in specific urban settings in *Belle Époque* France and Belgium; or for that matter within even wider parameters than those employed in this project?

Firstly, the thesis has uncovered new evidence about the historic use of a novel materials-system, as well as reanalysing existing evidence and commentary using a different methodological approach. Connections have also been made between the technical, societal and building design contexts for *Belle Époque* non-monumental, urban design and construction employing the novel materials-system. Secondly, it is clear that technical standards for engineering and construction, as well as other industrial sectors, have developed to represent a largely invisible but important feature of economy, society and the built environment. One could make an analogy with the first monolithic reinforced concrete and cement structural skeletons; even if not always visible in the facades of new buildings because of more aesthetically pressing reasons, the structurally efficient and fire-resistant building framing, floors and foundations were ever-present, and in many cases these then formed a holistic mass of a building, despite not always appearing to do so at 'facade value'. There were alternatives to reinforced concrete or cement systems in providing this (real and perceived) structural efficiency in a building, whether by using other metallic systems or even more traditional methods such as timber and masonry. But setting a metallic internal frame within 'artificial stone' offered an immediate inherent advantage in being plastic, so it could be shaped (on- or off-site) into any form within the physical boundaries set by the specific materials used and the structural limits of the building components constructed. The novel materials-system was also more fire resistant than timber or iron and steel alone. It offered potential economies of labour and scale, though this depended on supply and demand factors within the local construction industry.

The technical context of the research has focused on industrial patents for the novel materials-system, a key component of early industrial standards that codified the new technical knowledge needed to design and build the historic example buildings in and near the cities of Paris, Lille and Brussels during that later period of the *Belle Époque*. Industrial patents for the novel materials-system were employed together with structural specifications for the design and construction of new urban buildings. They were accompanied by technical guidance on the use of the novel materials-system by contemporaneous experts, many of whom became as a result specialist construction professionals. Industrial patents have continued to feed into regional, national and international regulations and codes that have controlled activity within the global built environment since the time of the *Belle Époque*. They were also a means by which the inventors of novel reinforced concrete and cement systems, particularly François Hennebique, could ensure an initial competitive advantage and so maximise their financial return on intellectual and capital investment. Each updated industrial patent might respond with incremental leaps forward in the technological sophistication of the reinforced concrete or cement systems employed, contributing together to an increasingly normalised materials-system for use by the construction sector. This in turn helped to simplify the key structural requirements of new *Belle Époque* non-monumental, urban buildings, that employed the new reinforced concrete and cement systems, and which included fire resistance, structural efficiency and daylight admission, subsequently also housing attributes linked to street decor, hygiene and affordability. Specialist building designers attempted to respond to the needs of building commissioners, within the constraints of the prevailing societal and building design context, as best as they could through these structural requirements.

While structural specifications were present in all good construction projects, they have tended to be more ephemeral, partly because the key technical written documents and drawings have not always been retained by businesses as essential pieces of information with an obvious long-term commercial or family value. Industrial patents connected with structural specifications for new buildings in what appeared to be, at least initially, an iterative process; this conclusion is based on previously unassessed evidence from the early employment of Hennebique's *béton armé* system in a building in the industrial North of France. The original technical workbook that exists in the Hennebique files in Paris for the Bossut-Masurel textile factory warehouse, completed in Roubaix near Lille in 1892, is therefore a valuable artefact; it provides useful information about a significant, since-demolished building with no records in local municipal archives and no indication of the architect involved.

The thesis has also considered the building design context of *Belle Époque* Eclecticism and its highly decorative *Art Nouveau* architectural genre, which flourished and then disappeared in France and Belgium in the space of a few decades in the lead up to the outbreak of continental war in 1914. This overlapped with the second stage of a metallic building design revolution (1892-1914), when new reinforced concrete and cement systems began to supplement the use of iron and steel, particularly in non-monumental, urban buildings. The question was asked in Chapter 5 whether an *Art Nouveau* architectural genre could have expressed itself sufficiently within the design parameters of at least some of the historic example buildings in the case studies in the thesis; no specific answer was provided at that stage, but broader observations were made about metallic approaches to design and construction associated with the more radically decorative genre. In Chapter 6, when applying the historical mechanism to the design and construction of the *immeuble* at 25b rue Benjamin Franklin, it was confirmed that the use of decorative ceramic tiles on the street facades of such buildings served as protection for the reinforced concrete skeleton beneath. Equally, Auguste Perret maintained that he had followed Viollet-le-Duc's praise of the tiling of Persian mosques, used as a mediating decorative skin that still allowed the underlying structural composition to be expressed fully. The building also raised issues about how emerging design and build specialists in the novel materials-system were caught between conservatism and radicalism in their technical design and construction of buildings, ignoring any conforming regulatory pressures that may have applied to their building projects – the latter connecting to the 1902 revision of Parisian street regulations covered in Chapter 4, designed to allow greater expressive freedoms for *Art Nouveau* architects in particular, but with mixed results in the end.

As the nineteenth century drew to a close and new communications and power technologies came to the fore, inevitably there was a backlash to the accepted forms of industrialisation. This connected to the emergence of Taylorism and Fordism as new controlling business management techniques that were then expressed through the design of 'daylight' or 'rational' factories in North America – the thesis has shown that the origins of the 'daylight factory' architectural typology can be linked back to the use of the *béton armé* system for Charles Six's wool-combing mill in Tourcoing completed in 1897, as well as similar industrial buildings constructed using the novel materials-system in and near Lille, Paris and elsewhere in Europe. Associated with this development was the interwar trope propagated by Le Corbusier, Gropius and their International Modernist peers described in Chapter 2. It is interesting to note that the design and construction of many skyscrapers in North American cities since the late nineteenth century, from whence one might argue that 'daylight factories' had also been derived as a 'horizontal' interpretation of the earlier vertical architectural typology, had been based on the rise of steel as a dominant metallic structural system transferred from the vital railroad network. There is, by contrast, relatively little research on the early use of reinforced concrete or cement in North American skyscrapers apart from the first one, the Ingalls Building completed in Cincinnati in 1903 (referenced in Chapters 1 and 6), as well as some on their interwar development in Seattle connected to specialised local economics.[426]

The broader analysis in the thesis covers new social concerns during the *Belle Époque* about the urban condition, as the rapidly expanding metropolises of France and Belgium started to groan with the burden of crowded populations, within which fatally contagious diseases might spread far too easily. Religion could no longer provide a sufficient remedy and newly-empowered humans could now use modern science and engineering to change all of their societies for the better. Buildings were at once part of the problem and

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[426] See Tyler Sprague, 'Products of Place: The Era of Reinforced-Concrete Skyscrapers in Seattle, 1921-1931', *Pacific Northwest Quarterly* 106, no. 3 (2015): 107–19.

provided possible solutions to urban ills, hence well into the twentieth century unhygienic and cramped tenement housing was gradually converted into clean urban accommodation available at affordable rents to the working classes. Benevolent housing associations swept through cities, despite initial resistance from property owners and even their tenants, who may have grown comfortable with their squalid lives. Governments became more empowered through democratic systems to take greater control of the everyday construction process, not simply to commission monumental architecture designed to please the more powerful members of society. The desolate aftermath of the Great War was truly a watershed moment for all, re-emphasised by the tragic repetition that would constitute the Second World War within a little over twenty years. The old approaches had clearly failed and faith was placed more and more in an International Modernist movement that wished to integrate industrialisation within a peace-loving society, or so it was hoped.

Bibliography

Primary materials

National archives

Archives Nationales du Monde de Travail, Roubaix (ANMT)

Pelnard-Considère-Caquot files 1994 035 0190 and 1994 035 0191 (*La Cathédrale,* Menier Chocolate Factory, Noisiel-sur-Marne), 1994 035 4192 (Armand Considère).

Centre d'archives d'architecture contemporaine, Paris (CAAC)[427]

Bétons armés Hennebique (BAH), *bureau technique central*:

76 IFA 1/3 J/h/5/G/1 (*immeuble* at 9 rue Claude Chahu, Paris)

76 IFA 9/8, 1354/20, 1556/4, 2560/1 and 2583/9 (HBM complex at rue de la Saïda, Paris)

76 IFA 54/15, 1102/7, 3629/2 (*Entrepôt Royal B* import warehouse, Brussels)

76 IFA 62/9, 1046/6, 1059/21, 1085/6 (*La Cathédrale*, Chocolaterie Menier, Noisiel-sur-Marne)

76 IFA 137/29 (Léon Govaerts, 300 m tower project painting)

76 IFA 108/10 and 1212/6 (Annex of the *Archives Départementales du Nord*, Lille)

76 IFA 1433/16 C/b/20/G/1 (*immeuble* at 185 rue Belliard, Paris)

76 IFA 2933/4 (Bossut-Masurel textile warehouse, Roubaix)

76 IFA 3540/3, 3653/9, 1/1, 100/1 (*immeuble* at 1 rue Danton, Paris)

76 IFA 3540/12 (Charles Six wool-combing mill, Tourcoing)

Perret, Auguste et Perret frères:

535 AP 52/1-14, 908, 401/2, 650/4 (*immeuble* at 25b rue Benjamin Franklin, Paris)

Sauvage, Henri (1873-1932):

18 IFA B6/20, 22-23, 27 and BR2 (Photographs of buildings/designs by Henri Sauvage including the HBM at 7 rue de Trétaigne, Paris)

18 IFA 203/5 (*immeuble* at 26 rue Vavin, Paris)

[427] The *Centre d'archives d'architecture contemporaine* (CAAC) in Paris was closed until the end of 2021 due to a move to new premises in Paris, as well as the after effects of the COVID-19 pandemic. CAAC has made a selection of visual images from its archives publicly accessible at: https://archiwebture.citedelarchitecture.fr/ (accessed 27/12/2023).

18 IFA 203/6 and 300/12 (*Immeuble Majorelle* at 124-6 rue de Provence, Paris)

Local archives

Archives Départmentales du Nord, Lille (ADN)

M4178309 (Charles Six wool-combing mill, Tourcoing)

79 J629-32, J629-34, J630-1 and J646-7 (Wool-conditioning complex, Roubaix)

4 N 232 and 628, 32 J/428 and 429 (Annex of the *Archives Départementales du Nord,* Lille)

Archives du Mairie de Noisiel-sur-Marne (AMN)

Files sent by the archivist (*La Cathédrale,* Menier Chocolate Factory, Noisiel-sur-Marne)

Archives Municipales de Tourcoing (AMT)

146 01B 1S3 Permis de Construire, 1913 (Charles Six wool-combing mill, Tourcoing)

Archives de Paris (AP)[428]

1849W 3 and 1752 W 98 (*immeuble* at 1 rue Danton, Paris)

3588W 144 (*immeuble* at 124-6 rue de Provence, Paris)

Archives de la Société Foncière La SAMARITAINE, Paris (ASFS)

Files sent by the archivist (*La Samaritaine* department store, Paris)

Archives du Ville de Bruxelles (AVB)

TP 14183 (Extension to *Banque Brunner*, Brussels)

TP 117520 and TP 110773 (*Entrepôt Royal B* import warehouse, Brussels)

Archives du Ville de Roubaix (AVR)

5 M 165, 174 310W, 333 W 3/17, 334 W5/1, 359 W 45 (Wool-conditioning complex, Roubaix)

11 W 23/4 and 7C53 (Motte family files)

Centre for Information, Documentation and Exhibitions on the city, architecture, landscape and urban planning in the Brussels-Capital Region (CIVA)

Léon Jean Joseph Govaerts file (1860-1930)

Urban Brussels (UB)

Commission Royale de Monuments et Sites (CRMS): Rue Marconi 32, 1996-2007; Ancienne Banque Brunner, Loi (rue de la) 78, Ville de Bruxelles, 1991-1997.

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[428] Unfortunately many original planning documents on *Belle Époque* buildings held at the *Archives de Paris* had been contaminated with asbestos, so remained inaccessible to me during my research. Some of these had been scanned, particularly those associated with Henri Sauvage, and were kindly sent to me by the archivists. Where relevant they are included as figures in the thesis.

Ministère de la region de Bruxelles-Capitale - 2322/Mon32 and 2322 0032-0 (HBM at 32 rue Marconi, Brussels)

Protection - Ancienne Banque Brunner, Loi (rue de la) 78, Ville de Bruxelles. 1b (2043-0251, Boîte 79)

Travaux - Loi 78 (rue de la), Ville de Bruxelles ("Ancienne Banque Brunner"), 2014. 1f (TR 2850) Études préalables.

Period articles and papers

Boileau, Louis-Charles. 'Le Rationalisme Gothique et La Raison Classique'. *L'Architecture* 3, 2 (1890): 13–15.

Boileau, Louis-Charles. 'Le Ciment Armé. Nouvelle Methode d'Application'. *L'Architecture* 8, 44 (1895): 369–70.

Boileau, Louis-Charles. 'Le Ciment Armé. Nouvelle Methode d'Application. Suite.' *L'Architecture* 8, 46 (1895): 388–91.

Boileau, Louis-Charles. 'Causerie. Art et Pratique'. *L'Architecture* 16, 32 (1903): 311–14.

Boileau, Louis-Charles. 'Causerie. Art et Pratique. Suite et Fin'. *L'Architecture* 16, 34 (1903): 331–34.

Boileau, Louis-Charles. 'Le Ciment Armé et l'Art de l'Architecture'. *L'Architecture* 18, 49 (1905): 454–57.

Bonnier, Louis. 'Les Nouveaux Règlements de Voirie a Paris'. *L'Architecture* 15, 35, 47-50, 52 (1902).

Bonnier, Louis. 'Les Nouveaux Règlements de Voirie a Paris'. *L'Architecture* 16, 1-4, 6-8, 10, 12 (1903).

Cloquet, Louis. 'L'Emploi Du Béton Armé En Architecture'. *Le Béton Armé* 11, 117 (1908): 22–23.

Debosque-Bonte. 'Dépot d'Archives Départementales Rue Jacquemare-Giellé, à Lille'. *Le Béton Armé* 12, 132 (1909): 75-76.

'Des Vues Photographiques de La Couverture Du Béton Armé'. *Le Béton Armé* 1, 5 (1898): 6.

Escande, Louis. 'Les Grands Travaux de La Samaritaine (Suite)'. *La Technique Des Travaux*, December 1933.

'Ferro-Concrete at the Front'. *Ferroconcrete* 6, 7 (1915): 249–50.

Flament, Georges. 'Quatrième Congrès Du Béton Armé. Séance Du Mardi Soir, 21 Août 1900'. *Le Béton Armé*, 3, 29 (1900): 1-11.

Forthuny, Pascal, and Édouard Arnaud. 'Le Ciment Armé Du Rue Danton à Paris'. *Le Béton Armé* 3, 36 (1901): 1-5.

Frantz, H. 'The Rothschild Artizans Dwellings in Paris Designed by Augustin Rey'. *The International Studio* 110 (April 1906): 115–28.

Gallotti, Paul. 'Le Béton Armé a l'Exposition de Lille'. *Le Béton Armé* 5, 53 (1902): 76-80.

Gallotti, Paul. ‘Le 6ème Congrès Du Béton Armé’. *Le Béton Armé*, 5, 45 (1902): 113–15.

Gallotti, Paul. ‘Théorie et Bluff’. *Le Béton Armé*, 15, 165-166 (1912): 41-42.

George, L, G. Olive, and G. Rozet. ‘XXXe Congrès Des Architectes Français. Séances, Visites, Excursion. Compte Rendu Sommaire (Suite).’ *L’Architecture* 15, 27 (1902): 221–24.

Hennebique, François. ‘Troisième Congrès Du Béton de Ciment Armé. Séance Du Mardi Soir 24 Janvier 1899.’ *Le Béton Armé* 1, 11 (1899): 1-5.

Hennebique, François. ‘Troisième Congrès Du Béton de Ciment Armé. Séance Du Mardi Soir 24 Janvier 1899.’ *Le Béton Armé* 1, 12 (1899): 1-9.

Hennebique, François. ‘Nécrologie Pour Édouard Hennebique’. *Le Béton Armé* 2, 15 (1899): 1.

Hennebique, François. ‘Quatrième Congrès Du Béton Armé. Séance Du Dimanche 19 Août 1900.’ *Le Béton Armé* 3, 28 (1900): 1-14.

‘Industries d’art, Les Écoles et Les Musées d’art Dans Les Départements’. *L’architecture et La Construction dans Le Nord* 8, 2 (1898): 13–18.

‘La Maison Des Dames Des Postes, Télégraphes et Téléphones’. *La Construction Moderne* 22, 15 (1907): 173–75.

‘L’annexe Des Archives Départementales Du Nord à Lille’. *La Construction Moderne* 25, 26 (1910): 303–5.

‘La Revision Du Décret Du 22 Juillet 1882 Sur Les Saillies à Paris’, 3 April 1897. *L’Architecture* 10, 14 (1897): 113-14

‘L’emploi Du Béton Armé Dans Le Bâtiment La Maison de La Rue Claude-Chahu’. *Le Béton Armé* 6, 67 (1903): 101-103

‘Le Nouvel Entrepôt de Bruxelles’. *Le Béton Armé* 9, 97 (1906): 73–75.

‘M. Trouillot à Montmartre’, *L’Humanité*. 4 July 1904.

‘Maison de Rapport Rue Danton No.1 à Paris’. *Le Béton Armé* 4, 41 (1901): 57–63.

‘Maison Potin, Rue de Rennes, Paris’. *La Construction Moderne* 10, 13 (1904): 149.

‘Maison, Rue Claude-Chahu, A Paris’. *La Construction Moderne* 8, 31 (1903): 365–66.

‘Maison Rue Danton à Paris’. *La Construction Moderne* 6, 28, 29, 31, 33 (1901).

‘Relevé Des Travaux Executés 1902’. *Le Béton Armé* (1902): 1-125.

‘Resultats Des Adjudications’. *La Semaine Des Constructeurs* 2, 6 (1887).

‘Société Des Logements Hygiéniques à Bon Marché’. *La Construction Moderne* 9, 41 (1904): 492.

Saunier, Charles. ‘Nouvelles Applications Du Gres Flammé Au Revêtement Des Façades’. *L’Architecte*, November 1908, 83–87.

Viennot. ‘Lettre de Viennot’. *L’Architecture* 20, 19 (1907): 149.

Editions from the following publications were also consulted during research for the thesis:

Annales des Ponts et Chaussées

Architectural Review

Bulletin de la Société Belge des Ingénieurs et des Industriels

Bulletin de la Société d'Encouragement pour l'Industrie Nationale

Concrete & Constructional Engineering

L'Architecte Constructeur

L'Architecture Usuelle

L'Art et les Artistes

La Genie Civil

La Houille Blanche

Le Ciment

Le Pantheon de l’industrie

Magazine of Art

Revue de l'Hygiène et Police Sanitaire

Revue des Arts Décoratifs

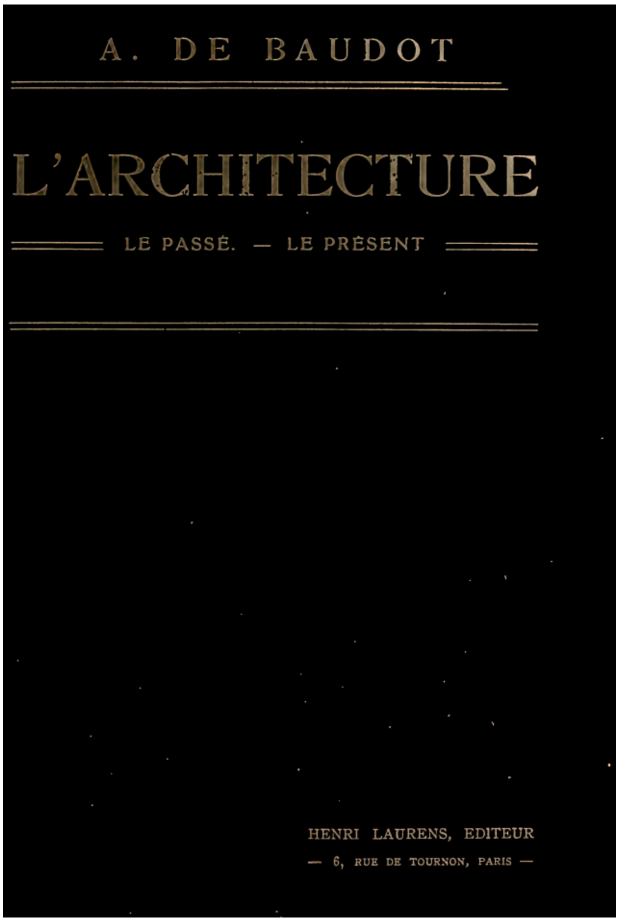
The American Architect

The Builders Journal and Architectural Engineer

Period books and pamphlets

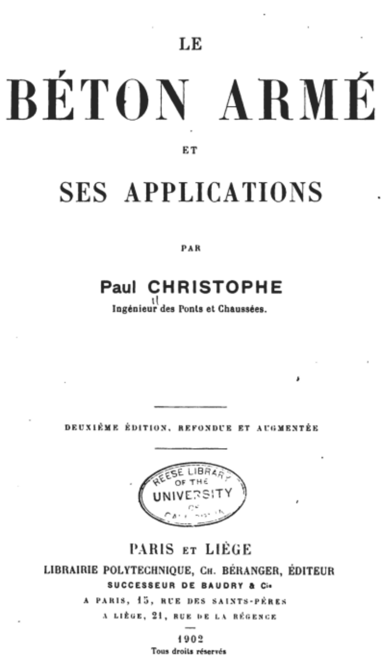
Arnaud, Édouard. *Cours d’Architecture et de Constructions Civiles*. Paris. 1921.

Baudot, Anatole de. *L’Architecture, Le Passé, Le Présent*. Edited by Henri Laurens. Paris. 1916.



Choisy, Auguste. *L'Histoire de L'Architecture, Tome II*. Geneva-Paris: Slatkine Reprints. 1899.

Christophe, Paul. *Le Béton Armé et Ses Applications*. 2nd ed. Paris: Beranger. 1902.



LE

BÉTON ARMÉ

ET

SES APPLICATIONS

PAR

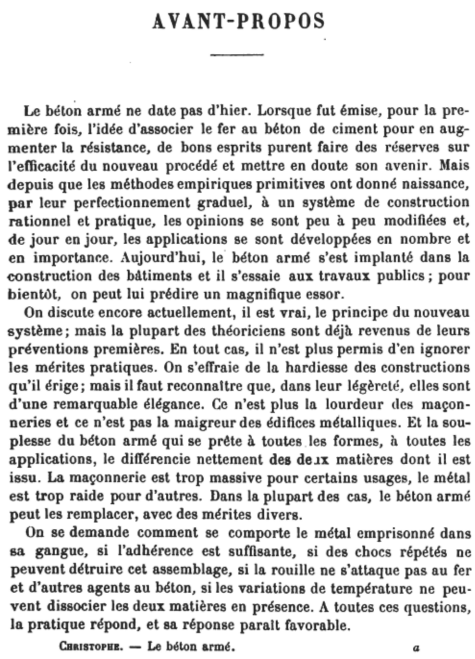
Paul CHRISTOPHE
Ingénieur des Ponts et Chaussées.

DEUXIÈME ÉDITION, REFONDUE ET AUGMENTÉE

PARIS ET LIÈGE
LIBRAIRIE POLYTECHNIQUE, CH. BÉRANGER, ÉDITEUR
SUCCESSEUR DE BAUDRY & Cie
A PARIS, 15, RUE DES SAINTS-PÈRES
A LIÈGE, 21, RUE DE LA RÉGENCE

1902

Tous droits réservés



AVANT-PROPOS

Le béton armé ne date pas d'hier. Lorsque fut émise, pour la première fois, l'idée d'associer le fer au béton de ciment pour en augmenter la résistance, de bons esprits purent faire des réserves sur l'efficacité du nouveau procédé et mettre en doute son avenir. Mais depuis que les méthodes empiriques primitives ont donné naissance, par leur perfectionnement graduel, à un système de construction rationnel et pratique, les opinions se sont peu à peu modifiées et, de jour en jour, les applications se sont développées en nombre et en importance. Aujourd'hui, le béton armé s'est implanté dans la construction des bâtiments et il s'essaie aux travaux publics; pour bientôt, on peut lui prédire un magnifique essor.

On discute encore actuellement, il est vrai, le principe du nouveau système; mais la plupart des théoriciens sont déjà revenus de leurs préventions premières. En tout cas, il n'est plus permis d'en ignorer les mérites pratiques. On s'effraie de la hardiesse des constructions qu'il érige; mais il faut reconnaître que, dans leur légèreté, elles sont d'une remarquable élégance. Ce n'est plus la lourdeur des maçonneries et ce n'est pas la maigreur des édifices métalliques. Et la souplesse du béton armé qui se prête à toutes les formes, à toutes les applications, le différencie nettement des deux matières dont il est issu. La maçonnerie est trop massive pour certains usages, le métal est trop raide pour d'autres. Dans la plupart des cas, le béton armé peut les remplacer, avec des mérites divers.

On se demande comment se comporte le métal emprisonné dans sa gangue, si l'adhérence est suffisante, si des chocs répétés ne peuvent détruire cet assemblage, si la rouille ne s'attaque pas au fer et d'autres agents au béton, si les variations de température ne peuvent dissocier les deux matières en présence. A toutes ces questions, la pratique répond, et sa réponse paraît favorable.

CHRISTOPHE. — Le béton armé. a

Colby, Albert Ladd. *Reinforced Concrete in Europe*. Easton: The Chemical Publishing Co. 1909.

Compressol. n.d. “Problèmes Des Fondations”. La Société de Fondation par Compression Mécanique du Sol.

Considère, Armand. *Experimental Researches on Reinforced Concrete*. 2nd ed. New York: McGraw Publishing Company. 1906.

Considère, Armand. *La Société de Fondation Par Compression Mécanique Du Sol Contre Le Béton Fretté.* Paris: Considère. 1911.

Corbusier, Le. *Towards a New Architecture*. London: J. Rodker. 1927.

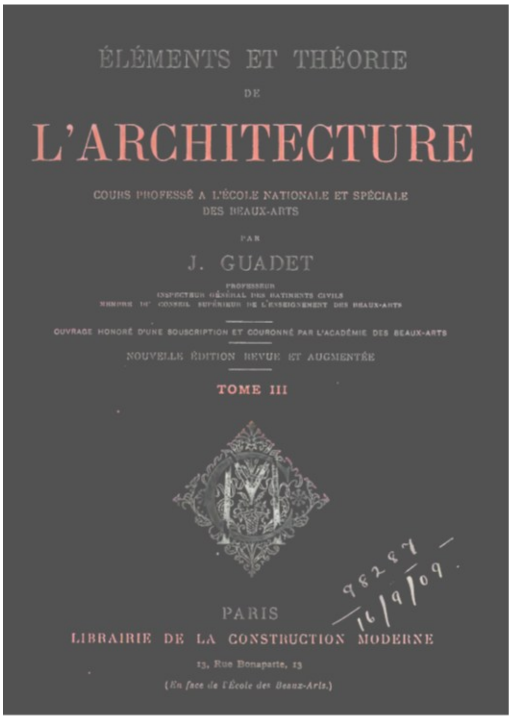
Coularou, Louis. “Le Béton Armé et Ses Applications”. Pamphlet. n.d.

Donaldson, Thomas Leverton and W. Cunningham Glen. *Handbook of Specifications: Or, Practical Guide to the Architect, Engineer, Surveyor, and Builder, in Drawing up Specifications and Contracts for Works and Constructions. Illustrated by Precedents of Buildings Actually Executed ... Preceded by a Preliminary Essay, Forms of Specifications and Contracts, &c. ...* London: Atchley and Co. 1860.

Eiffel, Gustave. *Travaux Scientifiques Exécutés à La Tour de 300 Mètres, de 1889 à 1900’. In La Tour de Trois Cents Mètres.* Paris: L. Maretheux. 1900.

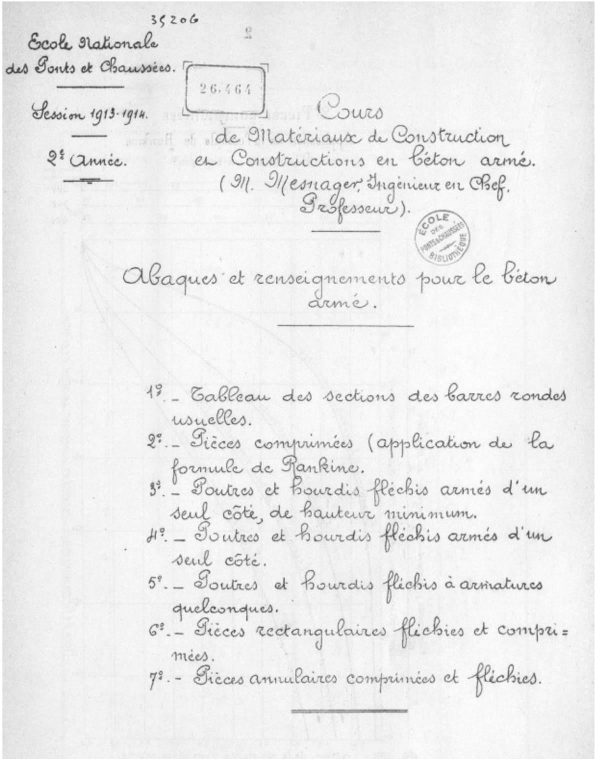
Gélis-Didot, Pierre. *Paris Mansions & Apartments 1893*. English language 2011 introduction by Christopher Drew Armstrong. Mineola: Dover Publications Inc. 1893.

Guadet, Julien. *Éléments et Théorie de L’Architecture*. Paris: Librairie de la Construction Moderne. 1894.



Lecoeur, Pierre. “Béton Armé Constructions Industrielles”. Paris. n.d.

Mesnager, Augustin. *Cours de Matériaux de Construction En Constructions en Béton Armé*. Paris: École des Ponts et Chaussées. 1914.



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Session 1913-1914.

2e Année.

Cours
de Matériaux de Construction
et Constructions en béton armé.
(M. Mesnager, Ingénieur en Chef,
Professeur).

Abaques et renseignements pour le béton armé.

1°. – Tableau des sections des barres rondes usuelles.
2°. – Pièces comprimées (application de la formule de Rankine.
3°. – Poutres et hourdis fléchis armés d'un seul côté, de hauteur minimum.
4°. – Poutres et hourdis fléchis armés d'un seul côté.
5°. – Poutres et hourdis fléchis à armatures quelconques.
6°. – Pièces rectangulaires fléchies et comprimées.
7°. – Pièces annulaires comprimées et fléchies.

Viollet-le-Duc, Eugène-Emmanuel. *Lectures on Architecture. Volumes 1 and 2*. Translation. London: Sampson Low, Marston, Searle and Rivington. 1881.

Wolfe Barry, John. *The Standardization of Engineering Materials, and Its Influence on the Prosperity of the Country. The James Forrest Lecture 1917*. London. 1917.

Woolson, I.H. *Report of the Proceedings of the International Fire Prevention Congress 1903*. New York. 1904.

Secondary materials

Books and chapters

Abram, Joseph. *Auguste Perret*. 2nd ed. Paris: Éditions du Patrimoine. 2013.

Addis, Bill. *Creativity and Innovation: The Structural Engineer's Contribution to Design*. Oxford: Architectural Press. 2001.

Addis, Bill. 'The Iron Revolution. How Iron Replaced Traditional Structural Materials Between 1770 and 1870'. In *Before Steel. The Introduction of Structural Iron and Its Consequences*, edited by Mario Rinke and Joseph Schwartz, 33-48. Sulgen/Zürich: Verlag Niggli AG. 2010.

Addis, Bill. 'The Soul of Iron and Its Revelation in Construction'. In *Konstruktionssprachen*, 61–72. De Gruyter. 2020.

Banham, Reyner. 1960. *Theory and Design in the First Machine Age*. Paperback (1972). Oxford: Architectural Press.

Banham, Reyner. *A Concrete Atlantis. US Industrial Building and European Modern Architecture*. Cambridge, Massachusetts: MIT Press. 1986.

Belhoste, Jean-Francois. 'Les Debuts Du Béton Armé et Son Introduction Dans Les Écoles d'ingénieurs et d'architecture'. In *Le Béton Armé. Histoire d'une Technique et Sauvegarde Du 20ème Siècle*, edited by Matteo Porrino. Paris: Infolio. 2019.

Belier, Corinne, Barry Bergdoll and Marc Le Coeur. 'Introduction'. In *Henri Labrouste. Structure Brought to Light*, edited by Ron Broadhurst, 20–23. New York: Museum of Modern Art. 2012.

Bennett, Andrew and Jeffrey T. Checkel. 'Process tracing From Philosophical Roots to Best Practices'. In *Process Tracing: From Metaphor to Analytic Tool*, edited by Colin Elman, John Gerring, and James Mahoney, 3–37. Cambridge: Cambridge University Press. 2015.

Bergdoll, Barry. 'The Crisis of Historicism'. In *European Architecture 1750-1880*, 269–80. Oxford: Oxford University Press. 2000.

Biggs, Lindy. *The Rational Factory. Architecture, Technology, and Work in America's Age of Mass Production*. Baltimore: Johns Hopkins University Press. 1996.

Billington, David. *The Art of Structural Design: A Swiss Legacy*. Princeton: Princeton University. 2003.

Blockley, David. *The New Penguin Dictionary of Civil Engineering*. London: Penguin. 2005.

Borsi, Franco, Robert Delevoy and Hans Wieser-Benedetti. *Bruxelles Capitale de l'Art Nouveau*. Rome: In Arch, Officina. 1972.

Bouchain, Patrick. *La Condition Publique, Roubaix*. Paris: Sujet-objet. 2004.

Bowley, Marian. *The British Building Industry. Four Studies in Response and Resistance to Change*. Cambridge: Cambridge University Press. 1966.

Bressani, Martin. 'Vers Une Politique Du Gout: Reflexions Sur Architectural Judgement'. In *Peter Collins and the Critical History of Modern Architecture*, edited by Irena Latek. Montreal: Institut de Recherche en histoire de l'architecture (IRHA). 2002.

Bressani, Martin. *Architecture and the Historical Imagination: Eugène-Emmanuel Viollet-Le-Duc*. Paperback 2017. Abingdon: Routledge. 2014.

Bucci, Federico. *Albert Kahn: Architect of Ford*. New York: Princeton Architectural Press. 2002.

Bullock, Nick, and James Read. *The Movement for Housing Reform in Germany and France 1840-1914*. Cambridge: CUP. 1985.

Carbonnier, Youri. *Les Premiers Logements Sociaux En France*. Paris: La Documentation Francaise. 2008.

Cartier, Claudine, Helene Jantzen, and Richard Michel. *Noisiel, La Chocolaterie Menier Seine-et-Marne*. 3rd ed. Île-de-France: Inventaire général, SPADEM. 1994.

Chevalier, Sebastien. *Le Paris Moderne. Histoire Des Politiques d'Hygiène (1855-1898)*. Rennes & Paris: Presses Universitaires de Rennes & Comité d'Histoire de la Ville de Paris. 2010.

Chrimes, Mike. 'Concrete Foundations and Substructures'. In *Historic Concrete Background to Appraisal*, edited by J. Sutherland, D. Humm, and M. Chrimes. London: Thomas Telford Publishing. 2001.

Clausen, Meredith L. *Frantz Jourdain and the Samaritaine: Art Nouveau Theory and Criticism*. Leiden: Brill. 1987.

Collins, Peter. *Changing Ideals in Modern Architecture 1750-1950*. London: Faber & Faber. 1965.

Collins, Peter. *Architectural Judgement*. London: Faber & Faber. 1971.

Collins, Peter. *Concrete. The Vision of a New Architecture*. 2nd ed. Montreal: McGill-Queen's University Press. 2004.

Conn, Peter. *The Divided Mind. Ideology and Imagination in America, 1898-1917*. Cambridge: Cambridge University Press. 1983.

Crouzet, Francois. *The Economic Development of France since 1870*. Vol. 1. Aldershot: Edward Elgar Publishing Ltd. 1993.

Daumas, Jean-Claude. *Les Territoires de la Laine. Histoire de l'industrie lainière en France au XIX siecle*. Villeneuve d'Ascq: Presses Universitaires du Septentrion. 2004.

Delhumeau, Gwenael. *L'invention Du Béton Armé : Hennebique, 1890-1914*. Paris: Éditions Norma. 1999.

Delhumeau, Gwenael, Jacques Gubler, Rejean Legault and Cyrille Simonnet. *Le béton en répresentation. La mémoire photographique de l'entreprise Hennebique 1890-1930*. Paris: Éditions Hazan. 1993.

Dierkens-Aubry, Françoise, and Jos Vandenbreeden. *Art Nouveau in Belgium. Architecture and Interior Design*. Paris: Duculot. 1991.

Dobbels, Jelena. 'The Road to Professionalization for Belgian General Contractors. An analysis of *La Chronique des travaux publics, du commerce et de l'industrie* (1877-1914)'. In *L'Architecture et l'Urbanisme du Long XIXe Siècle en Belqique. Lieux, protagonistes, rôles, enjeux et strategies professionnelles*, edited by Daniela N. Prina. Liège: Presses Universitaires de Liège. 2020.

Dumont, Marie-Jeanne. *Le Logement Social À Paris : 1850-1930. Les Habitations à Bon Marché*. Liege: Mardaga. 1991.

Épron, Jean-Pierre. *Comprendre L'Éclectisme*. Paris: Éditions Norma. 1997.

Fanelli, Giovanni and Roberto Gargiani. *Histoire de l'architecture Moderne. Structure et Revêtement*. Lausanne: Presses polytechniques et universitaires romandes. 2014.

Friedman, Donald. *Historical Building Construction: Design, Materials, and Technology*. New York & London: W.W. Norton & Co. 1995.

Harrison-Moore, Abigail and Dorothy C. Rowe. *Architecture and Design in Europe and America, 1750-2000*. Oxford: Blackwell Publishing Ltd. 2006.

Hub, Berthold. 'Architect Versus Engineer: Monumentality Versus Dematerialization'. In *Before Steel. The Introduction of Structural Iron and Its Consequences*, edited by Mario Rinke and Joseph Schwartz, 159-72. Sulgen/Zürich: Verlag Niggli AG. 2010.

Forty, Adrian. *Words and Buildings. A Vocabulary of Modern Architecture*. 1st ed. London: Thames & Hudson Ltd. 2000.

Forty, Adrian. *Concrete and Culture. A Material History*. Paperback ed. London: Reaktion Books Ltd. 2016.

Frampton, Kenneth. *Modern Architecture. A Critical History*. 4th ed. London: Thames & Hudson Ltd. 2007.

Giedion, Siegfried. *Space, Time and Architecture. The Growth of a New Tradition*. 5th ed. Cambridge: Harvard University Press. 1982.

Giedion, Siegfried. *Building in France. Building in Iron. Building in Ferro-Concrete*. Los Angeles: Getty Center for the History of Art and the Humanities. 1995.

Hildebrand, Grant. *Designing for Industry. The Architecture of Albert Kahn*. Cambridge, Massachussets: The MIT Press. 1974.

Hinchcliffe, Tanis. 'Peter Collins: The Voice from the Periphery'. In *Twentieth-Century Architecture and Its Histories*, edited by Louise Campbell, 177–94. Society of Architectural Historians of Great Britain.

Hitchcock, Henry-Russell and Philip Johnson. 1995. *The International Style*. 2nd ed. New York: W.W. Norton & Company, Inc. 2000.

Howard, Jeremy. *Art Nouveau. International and National Styles in Europe*. Manchester: Manchester University Press. 1996.

Jester, Thomas C. *Twentieth-Century Building Materials. History and Conservation*. 2nd ed. Los Angeles: Getty Conservation Institute. 2014.

Krohn, Carsten. *Walter Gropius Buildings and Projects*. Basel: Birkhauser Verlag GmbH. 2019.

Landes, David. 'Religion and Enterprise: The Case of the French Textile Industry'. In *Enterprise and Entrepreneurs in Nineteenth- and Twentieth-Century France*, edited by Edward C. Carter II, Robert Forster, and Joseph N. Moody, 41–86. Baltimore and London: The John Hopkins University Press. 1976.

Legault, Réjean. 'Between the Visible and the Legible. Iron and Reinforced Concrete in Fin-de-Siècle France'. In *The Companions to the History of Architecture, Nineteenth-Century Architecture Part II. Debates on Structure, Materials, and Tectonic Expression*, edited by Martin Bressani and Christina Contandriopoulous, 2:241–67. Online: John Wiley & Sons, Inc. 2017.

Lemoine, Bertrand. *L'Architecture Du Fer. France: XIXe Siècle*. Seyssel: Champ Vallon. 2008.

Lempereur, Hubert, and Jean-Francois Cabestan. *La Samaritaine, Paris*. Paris: Picard. 2015.

Levin, Miriam. 'Contexts of Control'. In *Cultures of Control*, edited by Miriam Levin. London: Routledge. 2004.

Loyer, Francois. *Le Siècle de L'Industrie*. Paris: Éditions d'Art Albert Skira. 1983.

Loyer, Francois. *Paris XIXe Siècle. L'Immeuble et La Rue*. Paris: Fernand Hazan. 1987.

Lussien-Maisonneuve, Marie-Joseph. 'Agrandir et Embellir Une Ville Industrielle (1851-1914)'. In *Histoire de Lille. Du XIXe Siècle Au Seuil Du XXIe Siècle*, edited by Louis Trenard and Yves-Mairie Hilaire. Lille: Librairie Academique Perrin. 1999.

Marrey, Bernard. *Louis Bonnier, 1856-1946*. Liège: Mardaga. 1988.

Marrey, Bernard, and Franck Hammoutène. *Le Béton à Paris*. Paris: Éditions du Pavillon de l'Arsenal/Picard Éditeur. 1999.

Mascarenhas-Mateus, João. *Changing Cultures: European Perspectives on the History of Portland Cement and Reinforced Concrete, 19th and 20th Centuries*. 1st ed. London: CRC Press. 2023.

Maury, Gilles. 'Procédés Constructifs et Matériaux'. In *Metamorphoses. La Réutilisation Du Patrimoine de l'âge Industriel Dans La Métropole Lilloise*, edited by Thierry Baert et al. Paris-New York: Le Passage. 2013.

Maury, Gilles. 'Effet Phenix. Les Architectes Du Nord de La France Au XIXe Siècle et l'incendie Industriel, Un Enjeu Professionel?' In *Risques Industriels. Savoirs, Régulations, Politiques d'assistance Fin XVIIe-Debut XXe Siècle*, edited by Thomas Le Roux. Rennes: Presses Universitaires de Rennes. 2016.

Mead, Christopher Curtis. *Making Modern Paris. Victor Baltard's Central Markets and the Urban Practice of Architecture*. University Park, Pa.: Pennsylvania State University. 2012.

Minnaert, Jean-Baptiste. *Henri Sauvage ou l'exercise du renouvellement*. Paris: Éditions Norma. 2002.

Minnaert, Jean-Baptiste. *Henri Sauvage*. Paris: Éditions du Patrimoine. 2011.

Minnaert, Jean-Baptiste, and Jean-Francois Pousse. *La Samaritaine. Une Renaissance Architecturale*. Paris: Archives d'architecture Moderne. 2022.

Muthesius, Stefan. *The English Terraced House.* New Haven: Yale University Press. 1982.

Newby, Frank. 'Innovative Uses of Concrete by Engineers and Architects'. In *Historic Concrete Background to Appraisal*, edited by James Sutherland, Dawn Humm, and Mike Chrimes, 11–44. London: Thomas Telford Publishing. 2001.

Oechslin, Werner. *Wagner, Loos, and the Road to Modern Architecture*. Translated by Lynette Weber. Cambridge: Cambridge University Press. 2002.

Pearlman, Jill. *Inventing American Modernism: Joseph Hudnut, Walter Gropius, and the Bauhaus legacy at Harvard*. Charlottesville and London: University of Virginia Press. 2007.

Peters, Tom F. *Building the Nineteenth Century*. Boston: MIT Press. 1996.

Peters, Tom F. ‘How the Introduction of Iron in Construction Changed and Developed Thought Patterns in Design’. In *Before Steel. The Introduction of Structural Iron and Its Consequences*, edited by Mario Rinke and Joseph Schwartz, 127-54. Sulgen/Zürich: Verlag Niggli AG. 2010.

Pevsner, Nikolaus. *Some Architectural Writers of the Nineteenth Century*. Oxford: Clarendon Press. 1972.

Pevsner, Nikolaus. *A History of Buildings. A.W. Mellon Lectures in the Fine Arts*. Bollingen Series XXXV, 19. Princeton: Princeton University Press. 1976.

Picon, Antoine. *French architects and engineers in the Age of Enlightenment*. Cambridge: Cambridge University Press. 1992.

Price, Roger. *An Economic History of Modern France, 1730-1914*. 2nd ed. London: The Macmillan Press Ltd. 1981.

Reichardt, Juergen. ‘Construction’. In *Albert Kahn’s Industrial Architecture. Form Follows Performance*, edited by Thorsten Buerklin and Jurgen Reichardt. Basel: Birkhaeuser. 2019.

Richaud, Gilbert. ‘The First Modern Concretes and the Rise of New Aesthetic Paradigms in 19th-Century France’. In *Changing Cultures. European Perspectives on the History of Portland Cement and Reinforced Concrete*, 19th and 20th Centuries. London: CRC Press. 2023.

Rykwert, Joseph. ‘The Rule and the Law’. In *Peter Collins and the Critical History of Modern Architecture*, edited by Irena Latek. Montreal: Institute de Recherche en histoire de l’architecture (IRHA). 2002.

Saint, Andrew. *Architect and Engineer: A Study in Sibling Rivalry*. Yale: Yale University Press. 2008.

Schmidt, Susanne K. and Raymund Werle. *Coordinating Technology. Studies in the International Standardization of Telecommunications*. Boston: MIT Press. 1998.

Simonnet, Cyrille. *Le Béton. Histoire d’un Matériau, Économie, Technique, Architecture*. Marseille: Éditions Parentheses. 2005.

Slaton, Amy E. *Reinforced Concrete and the Modernization of American Building, 1900–1930*. Kindle edition. Baltimore: Johns Hopkins University Press. 2001.

Smith, Terry. ‘Architecture and Mass Production: The Functionalism Question’. In *Making the Modern. Industry, Art and Design in America*. Chicago: University of Chicago Press. 1993.

Smith, Terry. ‘Albert Kahn: High Modernism and Actual Functionalism’. In *Albert Kahn, Inspiration for the Modern*, edited by Brian Carter. Ann Arbor: University of Michigan Museum of Art. 2001.

Steiner, Frances. *French Iron Architecture.* Studies in the Fine Arts: Architecture, No.3. Vol. 3. Ann Arbor: UMI Research Press. 1984.

Straub, Hans. *A History of Civil Engineering: An Outline from Ancient to Modern Times.* 1st publ. ed. Cambridge, Massachusetts: MIT Press. 1964.

Strike, James. *Construction into Design. The Influence of New Methods of Construction on Architectural Design 1690-1990*. Oxford: Butterworth-Heinemann Ltd. 1991.

Sutcliffe, Anthony. *Paris: An Architectural History*. New Haven and London: Yale University Press. 1993.

Thun-Hohenstein, Christoph and Sebastian Hackenschmidt. *Post Otto Wagner. Von Der Postsparkasse Zur Postmoderne.* Basel: MAK Birkhauser. 2017.

Trebilcock, Clive. *The Industrialization of the Continental Powers 1780-1914*. London and New York: Longman. 1981.

Troy, Nancy. *Modernism and the Decorative Arts in France: Art Nouveau to Le Corbusier*. Newhaven: Yale University Press. 1991.

Van der Woud, Auke. *The Art of Building: From Classicism to Modernity: The Dutch Architectural Debate 1840-1900*. Translated by Yvette Blankvoort and Bard Janssen. Aldershot: Ashgate Publishing Ltd. 2001.

Venturi, Robert, Denise Scott Brown and Steven Izenour. *Learning from Las Vegas*. Boston: The MIT Press. 1972

Williams, Richard J. *Reyner Banham Revisited*. London: Reaktion Books Ltd. 2021.

Yates, JoAnne and Craig N Murphy. *Engineering Rules. Global Standard Setting since 1880*. Baltimore: John Hopkins University Press. 2019.

Yeomans, David. *Construction Since 1900: Materials*. London: BT Batsford Ltd. 1997.

Journals and proceedings

Abram, Joseph. ‘An Unusual Organisation of Production: The Building Firm of the Perret Brothers, 1897-1954’. *Construction History* 3 (1987): 75–93.

Addis, Bill. ‘The Epistemology of Engineering Design as a Contribution to Construction History’. In *Studies in Construction History: The Proceedings of the Second Conference of the Construction History Society*, edited by James W.P. Campbell, Wendy Andrews, Amy Boyington, Gabriel Byng, Amy DeDonato, and Karey Draper, 3–10, 2015.

Belli-Riz, P. 'Le Béton Armé à La Recherche d'un Style'. In *Édifice et Artifice. Histoires Constructives. Actes Du 1er Congrès Francophone d'histoire de La Construction*, edited by R. Carvais, A. Guillerme, V. Nègre, and J. Sakarovitch, 641–50, 2010.

Bertels, Inge and Krista De Jonge. 'Building Specifications and the Growing Standardizing of Public Regulation in Nineteenth-Century Belgium'. In *Proceedings of the Third International Congress on Construction History*, edited by Karl-Eugen Kurrer, Werner Lorenz, and Volker Vetzk, 197–204, 2009.

Bonshek, Jane. 'The Skyscraper: A Catalyst of Change in the Chicago Construction Industries, 1882-1892'. *Construction History* 4 (1988): 53-74.

Bulckaen, Laurens and Rika Devos. 'The Engineer as Mediator in Complex Architectural Projects at the Turn of the Nineteenth Century: The Case Study of Louis Cloquet'. In I*ron, Steel and Buildings: Studies in the History of Construction. The Proceedings of the Seventh Annual Conference of the Construction History Society*, edited by James W.P. Campbell, Nina Baker, Karey Draper, Michael Driver, Michael Heaton, Yiting Pan, Natcha Ruamsanitwong, and David Yeomans, 405–18, 2020.

Bulckaen, Laurens and Rika Devos. 'The Ghent Booktower (1933–1947): A Product of Collaborating Professionals within Institutional Know-How'. In *History of Construction Cultures - Proceedings of the 7th International Congress on Construction History, 7ICCH 2021*, edited by João Mascarenhas-Mateus and Ana Paula Pires, 1:538–45, 2022.

Condit, Carl W. 'The First Reinforced-Concrete Skyscraper: The Ingalls Building in Cincinnati and Its Place in Structural History'. *Technology and Culture* 9, 1 (1968): 1–37.

Cusack, Patricia. 'François Hennebique: The Specialist Organisation and the Success of Ferro-Concrete: 1892-1909'. *Transactions of the Newcomen Society* 56, 1 (1984): 71–86.

Degraeve, Matthijs, Jelena Dobbels, Inge Bertels, Heidi Deneweth and Stephanie Van de Voorde. 'Spatial Management of Contractors. An Analysis of the Industrial Sites of the Louis De Waele Enterprise in Brussels (1867-1988)'. In *Building Knowledge, Constructing Histories. Volume 1 : Proceedings of the Sixth International Congress on Construction History*, edited by Ina Wouters, Stephanie van de Voorde, Inge Bertels, Bernard Espion, Krista de Jonge and Denis Zastavni, 527–35, 2018.

Denton, Steve, David Nethercot, Andrew Bond and Mariapia Angelino. 'Eurocodes Evolution: Latest Developments and UK Approach'. *The Structural Engineer*, March 2024, 12-14.

Devos, Rika and Bulckaen, Laurens. 'Collaboration in historical buildings: self-evident but intangible'. In *Construction Matters. Proceedings of the 8th International Congress on Construction History*, edited by Stefan Holzer, Silke Langenberg, Clemens Knobling and Orkun Kasap, 463-470, 2024.

Dumont, Marie-Jeanne. 'The Philosopher's Stone: Anatole de Baudot and the French Rationalists'. *Rassegna* 49, 1 (1992): 37–43.

Dunkeld, Malcolm. 'Approaches to Construction History'. *Construction History* 3 (1987): 3–15.

Espion, Bernard. 'La Renommée Internationale de La Belgique Dans l'Histoire Du Béton'. *Bruxelles Patrimoine*, no. 30 (2019).

Ford, Caroline. 'The Paris Housing Crisis and a Social Revolution in Domestic Architecture on the Eve of the First World War'. *Journal of Modern History* 90 (September 2018): 580–620.

Friedman, Donald. 'Building Code Enforced Evolution in Early Skeleton Buildings'. In *Proceedings of the Second International Congress on Construction History, Vol. 2*, edited by James W.P. Campbell, Wendy Andrews, Amy Boyington, Gabriel Byng, Amy DeDonato, and Karey Draper, 1171–87, 2006.

Gillet, Valentin. 'An Iron-Mounted Stoneware Façade in Paris: Charles Klein's Apartment Building at Rue Claude-Chahu 9'. In *Iron, Steel and Buildings: Studies in the History of Construction. The Proceedings of the Seventh Annual Conference of the Construction History Society*, edited by James W.P. Campbell, Nina Baker, Karey Draper, Michael Driver, Michael Heaton, Yiting Pan, Natcha Ruamsanitwong, and David Yeomans, 129–42, 2020.

Groak, Steven, and Graham Ive. 'Economics and Technological Change: Some Implications for the Study of the Building Industry'. *Habitat International* 10, 4 (1986): 115–32.

Hellebois, Armande, Yves Rammer and Jean-Claude Verbrugge. 'Concrete Piling: Major Developments in the Historical Practice of Pile Foundations'. In *Nuts and Bolts of Construction History, Proceedings of the Fourth International Congress on Construction History*, edited by R. Carvais, A. Guillerme, V. Nègre, and J. Sakarovitch, 581–91, 2012.

Hyde, Charles. 'Assembly-Line Architecture: Albert Kahn and the Evolution of the U.S. Auto Factory, 1905-1940'. *IA, The Journal of the Society for Industrial Archaeology* 22, 2 (1996): 5–24.

Jost, Hans-Ulrich. 'The Introduction of Reinforced Concrete in Switzerland (1890 to 1914): Social and Cultural Aspects'. In *Proceedings of the Second International Congress on Construction History Vol 2*, edited by

James W.P. Campbell, Wendy Andrews, Amy Boyington, Gabriel Byng, Amy DeDonato and Karey Draper, 1741–53, 2006.

Koetz, Laurent. 'Nineteenth Century Invention under Scrutiny. Louis-Auguste Boileau's Frame Construction Systems of around 1850.' In *Nuts & Bolts of Construction History. Proceedings of the Fourth International Congress on Construction History*, edited by R. Carvais, A. Guillerme, V. Nègre, and J. Sakarovitch, 185–92, 2012.

Kuban, Sabine. 'Innovation and Standstill - Early Application and Development of the "Monier System" in Berlin'. In *Proceedings of the 5th International Congress on Construction History, Chicago, Illinois. Vol 2.*, edited by B. Bowen, D. Friedman, T. Leslie, and J. Ochsendorf, 431–38, 2015.

Lampariello, Beatrice. 'Cells and *Epines-Contreforts* for a New Kind of Vaulted Roofing: The Church of Saint-Jean-de-Montmartre in Paris'. In *Studies in the History of Services and Construction: Proceedings of the Fifth Conference of the Construction History Society*, edited by James W.P. Campbell, Nina Baker, Amy Boyington, Michael Driver, Michael Heaton, Yiting Pan, Henrik Schoenefeldt, Michael Tutton and David Yeomans, 357–68, 2018.

Lawrence, Jeanne Catherine. 'Steel Frame Architecture versus the London Building Regulations: Selfridges, the Ritz, and American Technology'. *Construction History* 6 (1990): 23–46.

Leatt, Samuel. 'Owen Williams's Boots' "Wets" factory - a case study on the daylight factory typology'. In *Studies in the History of Services and Construction: Proceedings of the Fifth Conference of the Construction History Society*, edited by James W.P. Campbell, Nina Baker, Amy Boyington, Michael Driver, Michael Heaton, Yiting Pan, Henrik Schoenefeldt, Michael Tutton and David Yeomans, 129–40, 2018.

Leslie, Thomas. '"As Large as the Situation of the Columns Would Allow." Building Cladding and Plate Glass in the Chicago Skyscraper, 1885-1905'. *Technology and Culture* 49 (April 2008): 399–419.

Leslie, Thomas. 'Built like Bridges: Iron, Steel, and Rivets in the Nineteenth-Century Skyscraper'. *Journal of the Society of Architectural Historians*, 69, no. 2 (June 2010): 235-61.

Levy, Jack S. 'Preferences, Constraints, and Choices in July 1914'. *International Security* 15, 3 (1991): 151–86.

Lleo, Blanca. 'Steiff Factory, 1903. The Story of a Pioneer.' *RA Architecture* 22 (2020): 236–41

Mahoney, James. 'Process Tracing and Historical Explanation'. *Security Studies* 24, 2 (2015): 200–218.

Maury, Gilles. 'Albert Bouvy. Redécouverte de l'oeuvre d'un Architecte'. *Gens et Pierres de Roubaix*, February 2014.

McWilliam, Robert C. ‘The First British Standards: Specifications and Tests Published by the Engineering Standards Committee, 1903-18’. *Transactions of the Newcomen Society* 75 (2005): 261–87.

Merwood-Salisbury, Joanna. ‘Architecture as Model and Standard: Modern Liberalism and Tenement House Reform in New York City at the Turn of the Twentieth Century’. *Architectural Theory Review* 23, 3 (2019): 345–62.

Middleton, Robin D. ‘The Abbé de Cordemoy and the Graeco-Gothic Ideal: A Prelude to Romantic Classicism’. *Journal of the Warburg and Courtauld Institutes* 25, 4 (1962): 278–320.

Middleton, Robin D. ‘The Abbe de Cordemoy and the Graeco-Gothic Ideal. Part II.’ *Journal of the Warburg and Courtauld Institutes* 26, 1/2 (1963): 90–123.

Minnaert, Jean-Baptiste. ‘Henri Sauvage, Les Brevets et La Construction Rapide’. *Revue de l’Art* 118, 1 (1997): 41–55.

Packet, Tom. ‘Concrete Proposals: The Reception of Thomas A. Edison’s Monolithic Concrete House and Discussions on Mass-Produced Housing for the Working Classes in Pre-War Belgium, 1911-1913’. In *Proceedings of the Annual Conference of the Construction History Society*, edited by James W.P. Campbell, Nina Baker, Nicholas Bill, Michael Driver, Michael Heaton, Natcha Ruamsanitwong, Fiona Smyth and David Yeomans, 423-34, 2023.

Pavlović, Ana, Glen Rust and Harry Edwards. ‘Decarbonising Precast Concrete Manufacturing: Implementation of Low-Carbon Concretes’. In *Fib Symposium 2023*, edited by A Ilki et al, 418–28, 2023.

Peters, Tom F. ‘Education at the École Centrale in Paris and Its Influence on the Creation of Modern Iron Construction’. In *History of Construction Cultures - Proceedings of the 7th International Congress on Construction History, 7ICCH 2021*, 2:645–49, 2022.

Picon, Antoine. ‘Architecture, Technology and Imagination’. In T*he Place of Technology in Architectural History. Joint Symposium by the Society of Architectural Historians (GB) and the Construction History Society*, edited by H. Louw, 1-8. The Society of Architectural Historians of Great Britain, 2002.

Picon, Antoine. ‘Construction History: Between Technological and Cultural History’. *Construction History* 21 (2005): 5–19.

Portoghesi, Paolo and Franco Borsi. ‘Victor Horta Maison Du Peuple 1896’. *Architectural Design* 50, 1/2 (1980): 36–41.

Procida, Elisabetta. ‘Paul Cottancin, Ingénieur, Inventeur et Constructeur’. In *Édifice et Artifice. Histoires Constructives. Actes Du 1er Congrès Francophone d’histoire de La Construction*, edited by A R. Carvais, V. Guillerme, J. Nègre, and J. Sakarovitch, 599–607, 2010.

Puget, Julien. ‘Construction Market Organization in the 17th Century: Norms, Actors and Practices Examples of Extension Plans in Aix and Marseille.’ In *Nuts and Bolts of Construction History. Proceedings of the Fourth International Congress of Construction History*, edited by R. Carvais, A. Guillerme, V. Nègre, and J. Sakarovitch, 495–502, 2012.

Rauhut, Christoph. ‘Bauplatzstatik – How Structural Theory Altered Average Building Processes And How Daily Routine Influenced Structural Analysis’. In *Proceedings of the 5th International Congress on Construction History, Chicago, Illinois. Vol 3.*, edited by B. Bowen, D. Friedman, T. Leslie, and J. Ochsendorf, 163–70, 2015.

Richaud, Gilbert. ‘Francois Coignet (1814-88) and the *Industrial Development of the First Modern Concretes in France’. In Building Knowledge, Constructing Histories. Proceedings of the 6th International Congress on Construction History*, edited by Ina Wouters, Stephanie van de Voorde, Inge Bertels, Bernard Espion, Krista de Jonge and Denis Zastavni, 1121–28, 2018.

Saint, Andrew. ‘Rationalism, Technology and the Gothic Revival’. In *The Place of Technology in Architectural History. Joint Symposium by the Society of Architectural Historians (GB) and the Construction History Society*, edited by H. Louw, 19-25. The Society of Architectural Historians of Great Britain, 2002.

Saint, Andrew. ‘Architect and Engineer: A Study in Construction History’. *Construction History* 21 (2005): 21–30.

Seitz, Frédéric. ‘L’enseignement de l’architecture En France Au Xixe Siècle’. *Les Cahiers Du Centre de Recherches Historiques*, no. 11 (October 1993).

Shapiro, Ann-Louise. ‘Housing Reform in Paris: Social Space and Social Control’. *French Historical Studies* 12, 4 (1982): 486–507.

Sioc’han, Francoise. ‘Des Effets de La Houle Sur Les Ouvrages d’art: Application Des Moles Du Type “Considère” Dans La Protection Des Ports’. In *Construire ! : Entre Antiquité et Époque Contemporaine : Actes Du 3e Congrès Francophone d’histoire de La Construction, Nantes, 21-23 Juin 2017*, edited by Gilles Bienvenu, Martial Monteil, Hélène Rousteau-Chambon, Jean- Marie Guillouët, Marie- Paule Halgand, and Jean-Louis Kerouanton, 325–34, 2019.

Sprague, Tyler S. 'Products of Place: The Era of Reinforced-Concrete Skyscrapers in Seattle, 1921-1931.' *Pacific Northwest Quarterly* 106, 3 (2015): 107-19.

Stamper, John W. 'The Galerie Des Machines of the World's Fair, Paris'. *Technology and Culture* 30, 2 (1989): 330–53.

Summerson, John. 'What Is the History of Construction?' *Construction History* 1 (1985): 1–2.

Thorne, Robert. 'The Rebuilding of the Crystal Palace 1851-54: Permanent and Better?', *Construction History* (2019): 43–62.

Trout, Edwin A. R. 'The Deutscher Ausschuβ Für Eisenbeton (German Committee for Reinforced Concrete) 1907-1945. Part 1: Before World War I'. *Construction History* 29, 2 (2014): 51–71.

von Behr, Nick. 'The Patent War between François Hennebique and Armand Considère: Competing Reinforced Concrete Systems in "fin de Belle Époque" France'. In *Timber and Construction: Proceedings of the Ninth Conference of the Construction History Society*, edited by James W.P. Campbell, Nina Baker, Michael Driver, Michael Heaton, Natcha Ramsanitwong, Christine Wall, and David Yeomans, 373–85, 2022.

Voorde, Stephanie van de, Sabine Kuban and David Yeomans. 'Early Regulations and Guidelines on Reinforced Concrete in Europe (1900-1950). Towards an International Comparison.' In *Building Histories: The Proceedings of the Fourth Annual Conference of the Construction History Society*, edited by James W.P. Campbell, Nina Baker, Michael Driver, Michael Heaton, Yiting Pan, Treve Rosoman, Michael Tutton, and David Yeomans, 345-56, 2017.

Weber, Christiane. 'Les Bains Municipaux at Strasbourg (1905-1908) - an Example of Cultural and Technical Transfer between France and Germany'. In *Studies in Construction History: The Proceedings of the Second Construction History Society Conference*, edited by James W.P. Campbell, Wendy Andrews, Amy Boyington, Gabriel Byng, Amy DeDonato, and Karey Draper, 199–208, 2015.

Wermiel, Sara E. 'America's 19th-Century British-Style Fireproof Factories Background: Fireproof and Slow-Burning Construction'. *Industrial Archaeology* 27, 2 (2001): 23–36.

Wermiel, Sara E. 'The Development of Fireproof Construction in Great Britain and the United States in the Nineteenth Century'. *Construction History* 9 (1993): 3–26.

Wouters, Ine and Michael de Bouw. 'The Development of Fireproof Construction in Brussels between 1840-1870'. *Industrial Archaeology Review* 28, 1 (2006): 17-31.

Wouters, Ine, Stephanie van de Voorde, Marianne De Fosse and Inge Bertels. ‘Built to Stock. Versatility of Hennebique’s Urban Warehouses in Belgium (1892-1914)’. In *Building Knowledge, Constructing Histories. Volume 2 : Proceedings of the Sixth International Congress on Construction History (6ICCH), Brussels, Belgium, 9-13 July 2018*, edited by Ine Wouters, Stephanie van de Voorde, Inge Bertels, Bernard Espion, Krista de Jonge, and Denis Zastavni, 1383–91, 2018.

Zheng, H. and James W.P. Campbell. ‘History of Early Reinforced Concrete in Modern Shanghai, 1890-1914’. *Construction History* 36, 2 (2021): 81–122.

Theses

Addis, William. ‘Theory and Design in Civil and Structural Engineering. A Study in the History & Philosophy of Engineering’. University of Reading, 1986.

Angelino, Mariapia. ‘Developing Better Design Standards for the Construction Industry’. Bristol: University of Bristol, 2019.

Banham, Reyner (Peter). ‘The Theory of Modern Architecture 1907-1927’. University of London, 1958.

Basyn, Jean-Marc. ‘Léon Govaerts (1860-1930). Un Architecte de Transition’. Louvain-la-Neuve, 1992.

Biggs, Lindy. ‘Industry’s Master Machine: Factory Planning and Design in the Age of Mass Production, 1900 to 1930’. MIT, 1987.

Bressani, Martin. ‘Rationalism and the Organic Analogy in Fin-de-Siecle Paris: Auguste Perret and the Building at 25b Rue Franklin’. MIT, 1985.

Britton, Karla. ‘Auguste Perret’. Harvard University, 1997.

Clarke, Jonathan. ‘The Development of the Speculative Office in Inter-War England’. University of Cambridge, 2021.

Cusack, Patricia. ‘Reinforced Concrete in Britain: 1897-1908’. University of Edinburgh, 1981.

Deuten, Johannes Jasper. ‘Cosmopolitanising Technologies: A Study of Four Emerging Technological Regimes’. University of Twente, 2003.

Gillet, Valentin. ‘Conception et Confection Une Histoire Matérielle Du Revêtement Céramique Des Immeubles Parisiens (1900-1914)’. ETH Zurich, 2020.

Harper, Roger Henley. ‘The Evolution of The English Building Regulations 1840-1914’. University of Sheffield, 1978.

Hellebois, Armande. ‘Theoretical and Experimental Studies on Early Reinforced Concrete Structures’. Universite Libre de Bruxelles, 2013.

Legault, Réjean. ‘L’Appareil de L’Architecture Moderne: New Materials and Architectural Modernity in France, 1889-1934’. MIT, 1997.

Maulden, Robert. ‘Tectonics in Architecture’. MIT, 1986.

McWilliam, Robert C. ‘The Evolution of British Standards’. University of Reading, 2002.

Melsens, Sarah. ‘Architect, Engineer or Builder? A History of Professional Demarcation through Practice and Discourse, Pune (India) 1930-1992’. University of Antwerp, 2020.

Minnaert, Jean-Baptiste. ‘Henri Sauvage. Architecte (1873-1932)’. Université Paris IV – Sorbonne, 1993.

Mortensen, Jennifer L. ‘Reclaiming the Daylight Factory: The Significance of Versatility in the Preservation of Early Twentieth Century Concrete Frame Industrial Buildings in Dayton, Ohio’. University of Washington, 2015.

Prins, Megan De. ‘La Maison Du Peuple by Victor Horta: A Structural Analysis for the Reconstitution’. Vrije Universiteit Brussel and Université Libre de Bruxelles, 2016.

Singer, Guillaume. ‘Le Conditionnement de La Place Faidherbe à Roubaix’. University of Lille, 2001.

Slaton, Amy E. ‘Origins of a Modern Form: The Reinforced-Concrete Factory Building in America, 1900-1930’. University of Pennsylvania, 1995.

Traisnel, Jean-Pierre. ‘Le Métal et Le Verre Dans l’architecture En France. Du Mur à La Facade Legère’. Institut Français d’Urbanisme, 1997.

Turner, Paul. ‘The Education of Le Corbusier. A Study of the Development of Le Corbusier’s Thought, 1900-1920’. Harvard University, 1971.

von Behr, Nicholas. ‘The ‘dockisation’ of the Port of Bristol’. University of Bath, 1995.

Voorde, Stephanie van de. ‘Bouwen in Beton in België (1890-1975) Samenspel van Kennis, Experiment En Innovatie’. University of Ghent, 2011.

Reports

Abram, Joseph. *Perret et l’école du classicisme structurel (1910-1960)*. Nancy, 1985.

Apur. *Les Habitations à Bon Marché de La Ceinture de Paris : Étude Historique*. Paris, 2017.

DHAAP/DAC. *Les HBMs: Un Patrimoine Multiple (1894-1949)*. Paris, 2019.

Dion, Mathilde and Bernard Marrey. n.d. 'Louis Bonnier (1856-1946) Notices Biographiques'. Paris: Centre d'archives d'architecture du XXe siècle.

d'Oreye, Patricia. 'Notes Pour Le Projet d'une Étude Historique de l'Hôtel de Maître et de La Banque Brunner 78 Rue de La Loi, Bruxelles'. Brussels, 2015.

Dumont, Marie-Jeanne. *La Fondation Rothschild et Les Premières Habitations à Bon Marché de Paris, 1900-1925*. Paris, 1984.

Eleb, Monique. *HBM à Paris: Le 124-126 Avenue Daumesnil, d'Auguste Labussière, Fondation Groupe Des Maisons Ouvrières*. Paris, 1991.

Eleb, Monique and Anne Debarre-Blanchard. *Architectures de La Vie Privée. La Belle Époque de l'habitation, 1880-1914. Tome 2*. Paris, 1989.

Guidance Document for PAS 2080 Practical Action and Examples to Accelerate the Decarbonisation of Buildings and Infrastructure. London, 2023.

Lambert, Ray and Paul Temple. *The Relationship between Standards, Standards Development and Intellectual Property*. London, 2015.

Reichen & Robert. 'Report on Renovation Work at Menier Chocolate Factory, Noisiel-Sur-Marne'. Paris, 1992.

Appendices

A1. Additional Tables

Table 1.1: Historic example buildings in the case studies by reinforced concrete or cement system used and location

System used	Paris and environs	Lille and environs	Brussels
Béton armé system: 1892-3 French and Belgian patents		Bossut-Masurel textile factory warehouse, Roubaix (1893, demolished)	
Béton armé system: 1897 French and Belgian patents	*Immeubles* at 1 rue Danton, (1900) and 9 rue Claude-Chahu, Paris (1903)	Charles Six wool-combing mill, Tourcoing (1897, demolished)	*Banque Brunner* extension (1900)
Béton armé system: After 1903 legal case annulling Hennebique's French patents	HBM complex rue de la Saïda, Paris (1914)	Annex to *Archives Départementales du Nord*, Lille (1910)	The *Entrepôt Royal B* import warehouse (1906)
Other systems:	HBM 3 rue de Trétaigne, Paris (1904, unknown system) *Immeuble* at 185 rue Belliard, Paris (1913, Cottancin system) *La Cathédrale*, Menier Factory, Noisel-sur-Marne (1908, *béton fretté* and Viennot systems)	Wool-conditioning complex, Roubaix (1901, Coularou system)	HBM 32 rue Marconi (1902, *béton armé* system or a derivative)

Table 2.2: Historic example buildings in the case studies completed after the revised 1902 Paris street regulations

Building (Year completed)	**Reinforced concrete or cement system**	**Space effects**	**Projection effects**
Immeuble, 9 rue Claude-Chahu, Paris (1903)	*béton armé*	Large rear courtyard	Bay windows
HBM, 7 rue de Trétaigne, Paris (1904)	Unknown	Roof-terracing	Bay windows
Immeuble, 185 rue Belliard, Paris (1913)	Cottancin (derived)	Roof-terracing	Bay windows
HBM complex, rue de la Saïda, Paris (1913)	*béton armé*	Spaced blocks joined by open staircases	None

Table 3.2: The two typologies and their twelve historic buildings showing components using reinforced concrete or cement systems

Typology **Building (Year Completed)**	**Reinforced concrete or cement systems used**	**Used in building framing**	**Used in floors**	**Used in foundations**	**Design features (case study)**
1. Urban Industrial					
Charles Six wool-combing mill, Tourcoing near Lille (1897)	*béton armé* system	Yes	Yes	Not known	'Daylight factory', with no brick infill on its top three floors, rather floor to ceiling windows. Curved corner. Roof balustrade. ('daylight factories' case study, Chapter 2)
Extension to *Banque Brunner*, Brussels (1900)	*béton armé* system	Yes	Yes	Not known	Coupole roof with glazing to admit daylight. ('new urban design approach' case study, Chapter 5)
Wool-conditioning complex, Roubaix near Lille (1901)	Coularou system	No	Yes	No	3000m^2 roof-terracing on 39 unique iron matrix pillars. Polychrome brick infill with ceramic tiling. ('new urban design approach' case study, Chapter 5)
Import warehouse, *Entrepôt Royal B*, Brussels (1906)	*béton armé* and Compressol systems	Partially	Yes	Yes	Cantilevered walkways and skylights, small windows. Reinforced concrete pillar-beam-slab inside, but thick external supporting walls made of brick. ('new urban design approach' case study, Chapter 5)
Cocoa and sugar processing building, *La Cathédrale*, Noisiel-sur-Marne near Paris (1908)	*béton fretté* and Viennot systems	Yes	Yes	Yes	'Daylight factory' with some brick infill and large windows. Connected

Typology Building (Year Completed)	Reinforced concrete or cement systems used	Used in building framing	Used in floors	Used in foundations	Design features (case study)
					p*asserelle*. ('daylight factories' case study, Chapter 2)
Annex to *Archives Départementales du Nord*, Lille (1910)	*béton armé* system	Yes	Yes	No	Cantilevered walkways, skylights, no windows. Appears to be a self-supporting system within neighbouring walls. ('new urban design approach' case study, Chapter 5)
2. Urban Housing					
Immeuble, 1 rue Danton, Paris (1900)	*béton armé* system	Yes	Yes	Yes	Bay windows, set-back top balcony, roof-terracing, cement moulding on facade. (building case study, Chapter 4)
HBM, 32 rue Marconi, Brussels (1902)	*béton armé* system or more likely a derivative	Partially	Yes	No	Hybrid system using brick and reinforced concrete and cement. Cement moulding on facade. (HBM case study, Chapter 3)
Immeuble, 9 rue Claude-Chahu, Paris (1903)	*béton armé* system	Yes	Yes	Not known	Stoneware clad onto dual-skin walling of facade, bay windows. ('Parisian immeubles with decorative ceramic facade cladding' case study, Chapter 5)
HBM, 7 rue de Trétaigne, Paris (1904)	unknown system	Yes	No	Not known	Semi-visible building framing, glass bricks replaced by clay brick infills (lime-washed), bay and tailored

Typology Building (Year Completed)	Reinforced concrete or cement systems used	Used in building framing	Used in floors	Used in foundations	Design features (case study)
					windows, roof-terracing. (HBM case study, Chapter 3)
Immeuble, 185 rue Belliard, Paris (1913)	Cottancin system derivative	Yes	Yes	Not known	Geometric-shaped ceramic tiles on facade, bay windows. (‘Parisian immeubles with decorative ceramic facade cladding’ case study, Chapter 5)
HBM complex, rue de la Saïda, Paris (1914)	*béton armé* and Compressol systems	Yes	Yes	Yes	External staircases, polychrome brick and ceramic tiling on parts of the facades. (HBM case study, Chapter 3)

Table 3.4: Subsidiary research outcomes assessed by relative strengths and further research opportunities

No.	Research outcome	Relative strengths	Further research opportunities
1	Improving our knowledge of fourteen *Belle Époque* non-monumental, urban buildings.	Fourteen historic buildings have been filtered systematically from a database of more than 50 buildings and the descriptions used have reanalysed previous commentary as well as introduced new evidence, where available.	A fuller heritage preservation assessment of at least some of these historic buildings might add even more to our knowledge base. This could be done as Masters research projects where none already exist.
2	Contributing to a broader debate about historic role of novel materials-systems in construction, with particular reference to more structurally-efficient and fire-resistant non-monumental, urban buildings that used reinforced concrete and cement systems.	Provides more detail and analysis about early French reinforced concrete and cement systems within a novel materials-system for building design and construction.	The research boundaries could be broadened out to include the risk intermediary role of specialist contractors, as well as other novel early reinforced concrete and cement systems.
3	Reassessing the European origins of the North American ‘daylight’/’rational’ factory architectural typology.	Highlights the evidence gaps in the current state of research on this specific topic.	Finding new evidence about the contrasting North American and European context for the ‘daylight’/’rational’ factory.
4	Outlining the historical relationship between the societal demand for improved urban hygiene and the optimal technical design of urban accommodation, allowing for affordability and sustainability.	Provides a broader societal context to construction history research often focused on technical issues, so permitting a more interdisciplinary approach with its associated wider benefits to the research.	Ensuring that increased interdisciplinarity in the history of buildings and their construction does not take place at the expense of the contribution of the technical disciplines.
5	Endorsing the need for further research on the role of regulations and codes of building practice since the First World War and their tightening relationship with technical standards for reinforced concrete and cement systems.	Provides a case for continuing the chronology into the twentieth and twenty-first centuries , once the relationship between regulations and standards had become more embedded in a form we still recognise.	Combine research on the historical technological-aesthetic use of (reinforced) concrete in twentieth century North America, Europe and Britain, with research on developing better modern design standards and rules of professional conduct for the construction industry, learning for example from the ongoing process for revising all Eurocodes by 2026.

A2. Pre-First World War urban buildings in or near Paris, Lille and Brussels

The table includes historic urban buildings considered, referenced or used in the thesis, in order of their completion.

	Historic example building	How used	Location	Completed	Key metallic materials and systems
1	*Bibliothèque Saint-Geneviève*	Referenced	Paris	1851	Iron
2	*Gare du Nord*	Referenced	Paris	1864	Iron
3	*Bibliothèque National*	Referenced	Paris	1868	Iron
4	Menier chocolate factory cocoa mill	Referenced	Noisiel-sur-Marne	1872	Iron
5	*Les Halles*	Referenced	Paris	1874	Iron
6	*Printemps* department store	Referenced	Paris	1883	Iron
7	*Bon Marché* department store	Referenced	Paris	1887	Iron
8	Eiffel Tower	Referenced	Paris	1889	Iron
9	*La Galerie des Machines*	Referenced	Paris	1889	Steel
10	Bossut-Masurel textile warehouse	Historic example in case study	Roubaix	1892	*Béton armé*
11	*Hôtel Tassel*	Referenced	Brussels	1893	Iron
12	*Hôtel Solvay*	Considered	Brussels	1894	Iron
13	*Hôtel van Eetvelde*	Considered	Brussels	1895	Iron
14	Barrois frères factory	Referenced	Lille	1895	*Béton armé*
15	Charles Six wool-combing mill	Historic example (Urban Industrial)	Tourcoing	1897	*Béton armé*
16	*Ruelle* Chocolate factory	Considered	Brussels	1898	*Béton armé*
17	*Maison du Peuple*	Referenced	Brussels	1899	Iron

	Historic example building	How used	Location	Completed	Key metallic materials and systems
18	*Maison du Peuple*, rue de Clignacourt	Considered	Paris	1899	*Béton armé*
19	Old England department Store	Referenced	Brussels	1899	Steel
20	*Immeuble* at 1 rue Danton	Historic example (Urban Housing)	Paris	1900	*Béton armé*
21	Banque Brunner extension	Historic example (Urban Industrial)	Brussels	1900	*Béton armé*
22	Jules Waucquez & Cie warehouse	Considered	Brussels	1901	Reinforced concrete
23	Wool-conditioning complex	Historic example (Urban Industrial)	Roubaix	1901	Coularou system
24	HBM at 32 rue Marconi	Historic example (Urban Housing)	Brussels	1902	*Béton armé*
25	École des Soeurs de la Sagesse, Ave Victor Hugo	Considered	Paris	1903	*Béton armé*
26	*Immeuble* at 9 rue Claude-Chahu	Historic example (Urban Housing)	Paris	1903	*Béton armé*
27	Motte Bossut & Mengers factory	Referenced	Roubaix	1903	Coularou system
28	*Immeuble* at 25b rue Benjamin Franklin	Used with historical mechanism	Paris	1904	Coignet derived system
29	HBM at 7 rue de la Treitagne	Historic example	Paris	1904	Reinforced concrete

	Historic example building	How used	Location	Completed	Key metallic materials and systems
		(Urban Housing)			
30	*Immeuble* at *Cité L'Argentine* 111 ave Victor Hugo	Referenced	Paris	1904	Steel/Zinc
31	*Immeuble* at 124 rue Reamur	Referenced	Paris	1904	Steel
32	Villa Hennebique, Bourg-la-Reine	Considered	Paris	1905	*Béton armé*
33	Garage, 5 rue de Ponthieu	Referenced	Paris	1906	Reinforced concrete
34	*Entrepôt Royal B* import warehouse	Historic example (Urban Industrial)	Brussels	1906	*Béton armé*
35	*Immeuble* at 6 rue Hanovre	Considered	Paris	1907	*Béton armé*
36	*Société des Automobiles de Place* offices and showroom in Levallois-Perret	Considered	Paris	1907	*Béton armé* & Considère system
37	*Hôtel Carnot*	Considered	Paris	1908	Reinforced concrete
38	*La Cathédrale* cocoa and sugar combining mill, Menier factory	Historic example (Urban Industrial)	Noisiel-sur-Marne	1908	*Béton fretté* and Viennot system
39	HBM at 117 rue de Belleville	Considered	Paris	1908	*Béton armé*
40	*Hôtel Majestic*	Considered	Paris	1908	*Béton armé* and steel
41	HBM at 124-6 avenue Daumesnil	Referenced	Paris	1908	*Béton armé*
42	*Immeuble* at 15 rue Perrichont	Considered	Paris	1909	*Béton armé*
43	HBM at 165 Boulevard de l'Hôpital	Referenced	Paris	1909	Reinforced concrete

	Historic example building	How used	Location	Completed	Key metallic materials and systems
44	Annex to *Archives Départmentales du Nord*	Historic example (Urban Industrial)	Lille	1910	*Béton armé*
45	*La Samaritaine* Magasin 2	Referenced	Paris	1910	Steel and iron
46	*Hôtel Palace*	Considered	Brussels	1910	*Béton armé* and steel
47	*Hôtel Lutetia*	Considered	Paris	1910	*Béton armé* and steel
48	*Immeuble* at 95 boulevard Murat	Considered	Paris	1912	Reinforced concrete
49	*Théâtre des Champs Élysées*	Referenced	Paris	1912	Reinforced concrete
50	*Galeries Lafayette*	Referenced	Paris	1912	Steel
51	*Immeuble* at 47 Boulevard Bessieres	Considered	Paris	1913	*Béton armé*
52	*Immeuble* at 8 rue Armand Moisant	Considered	Paris	1913	*Béton fretté* system
53	*Immeuble* at 185 rue Belliard	Historic example (Urban Housing)	Paris	1913	Cottancin derived system
54	*Immeuble Majorelle* 124-6 rue de Provence	Referenced	Paris	1913	Piketty system
55	*Immeuble* at 26-8 rue Vavin	Referenced	Paris	1913	Piketty system
56	HBM complex rue de la Saïda	Historic example (Urban Housing)	Paris	1914	*Béton armé*

A3. Key terms and their definitions

The thesis uses a range of key terms for which some general definitions are provided below, in addition to the longer descriptions under Terminology towards the start.

Term	Definition
Architect	The professional status of a person responsible for the architectural design of a building or bridge.
(Archi)tectonic	Describing the structural aspects of architecture.
Avant-garde	Derived from a military term and used by Henri de Saint-Simon in 1825 to describe a radical new social-industrial movement powered by art, it gradually came to mean artistic expression that pushed the boundaries of social acceptability.
Cast iron	Pure iron which has been directly cast into moulds to produce solid shapes with a high carbon content. Can be stronger in compression than wrought iron, but equally, weaker in tension.
Cement	A mixture of water, sand and a curing agent (dry lime, pozzolana, Portland cement powder etc).
Civil and Structural Engineer	The professional status of a person ultimately responsible for the engineering and structural design of a construction work.
Concrete	A mixture of cement with aggregates.
Contractor	The person and/or organisation contractually responsible for carrying out construction work to successful and long-lasting completion. If they had a contractual arrangement with the owner of a reinforced concrete or cement system then they were known in French as *concessionnaires* (concessionaire or concessionary in English).
Design Procedure	Process by which a building is structurally designed by a civil or structural engineer.
Design Revolution	A watershed transition from a ‘normal’ to a ‘new’ paradigm for a communal Design Procedure.
Early industrial standard	The outcome of normalising technical information about a historic materials-system. It had three components: industrial patents, structural specifications and technical guidance.
Industrial patent	A legal document indicating the nature and extent of intellectual property rights for a novel materials-system.
Materials-system	Collective noun for reinforced concrete and cement systems used in building design and construction.

Term	Definition
Monolithic	Literally 'made from a single stone' or giving the appearance of this. A combination of building framing, flooring (and foundations) using a reinforced concrete or cement system in a holistic structural skeleton.
Reinforced Concrete or Cement	Concrete or cement with metallic internal framing (rebars). Can be formed on-site or off-site into (components of) structures. Reinforced concrete has good tensile and compressive strength and is cheaper per m^3 than steel.
Regulations or Codes (e.g. for hygiene, health & safety, design and construction processes, building components etc)	Compulsory local or national rules impacting on planning, design and construction in the urban environment. In time these have become international e.g. Eurocodes.
Steel	Pig iron worked at higher temperatures than cast and wrought iron to allow greater control of the carbon content, with some chemicals (re)added. Stronger in both compression and tension than cast and wrought iron and lighter per m^3.
Technical building design	The technical aspects of designing a building.
Structural efficiency	Describing the satisfactory structural performance of a building.
Structural requirements	Specific features required for the technical design of a building, converted from commissioner needs.
Structural specifications	The technical details of how a structure is to be built, as opposed to architectural specifications, which are broader.
Technical guidance	Technical information for specialist designers and constructors using a novel materials-system.
Wrought iron	Pig iron which has been worked to reduce its carbon content and extruded into lengths. Can be stronger in tension than cast iron, but equally, weaker in compression.