The introduction of new construction materials and the teaching of engineering based on technical intelligence: the role of Antão Almeida Garrett

Maria da Luz SAMPAIO
IHC - Faculdade de Ciências Sociais e Humanas da Universidade Nova de Lisboa, Lisboa, Portugal
E-mail : mluzsampaio@fsch.unl.pt
ORCID: 0000-0002-9231-4757

Abstract:

Through the teaching of engineering, the introduction of new materials into civil construction gained a privileged mean of circulating knowledge and stimulating the new construction experiences that shaped a technical intelligence within the scope of which there stood out the professor of the Faculty of Engineering of the University of Porto, including Francisco Xavier Esteves, Francisco Correia de Araújo and Antão Almeida Garrett.

This chapter's objective is to analyse the introduction of reinforcing cement and its interconnections with the study plans for engineering teaching at the University of Porto in the 1920s and 1930s, which were first structured around the Technical Faculty that later became the Engineering Faculty of Porto University. We correspondingly opted to identify some of the specific experiences and theoretical reflections around the application of this new construction material and highlighting the role of Antão Almeida Garrett and his purposes for advancing with the utilisation of reinforced cement in civil construction, especially in industrial buildings in Porto.

Keywords: engineering, intelligence, construction methods, reinforced concrete, affordable

1. Introduction

The teaching of engineering and the performance of their schools is a way to analyse the transmission of scientific knowledge and the production of an academic elite, an *intelligentsia* responsible for innovation and the circulation of knowledge.

We focus on the Engineering Faculty of Porto University, through the work of professor Antão de Almeida Garrett, in order to analyse the introduction of reinforced concrete in the decade of 1930, and we concluded that he belongs to a generation of engineering professors that improved the use of concrete and disseminated technical knowledge within the models created by education policies since 1911, under the republican government.

2. The utilisation of reinforced cement in civil construction in the early decades of the 20th century

At the beginning of the 20th century, there remained the construction practices, techniques and materials handed down from the 19th century. Limestone, wood (especially pine) applied to floor and roof structures and as well as forged iron with steel arriving later. The new materials were used to improve the construction mainly the connection between wood and the stonemasonry. (Appleton, 2004). According to Vale (2012) house building in the early decades of the 20th-century continued to prefer resistant stonemasonry walls, floors and roofs in wooden structures, varying in their quality in accordance with the economic resources available.

One of the materials that would progressively expand in utilisation throughout construction, was Portland cement and over the course of the 20th-century the use of reinforced concrete: this new material had the advantage of fire resistance; the possibility of realizing large spans; economy, speed; and improved quality in the construction (Póvoas, 2015).

Since the second half of the 19th-century progress in transport and communications onwards ensured the next century began with a better understanding of the functioning of materials especially the scope for concrete and its respective typologies. This development interlinked with the registering of numerous patents and other successful applications that brought about its adoption for facades, beams and other structural features. The development of this new material arose from various contributions and experiences, especially those of:

- Louis Vicat (1786- 1861), graduated in engineering at École Polytechnique de Paris and École Nationale des Ponts et Chaussées;
- the chemical engineer François Coignet (1814-1888), deemed the inventor of reinforced cement applied to building structure (Mascarenhas-Mateus, 2018);

- the German engineer Matthias Koenen (1894-1924), the first to do structural calculation of reinforced concrete elements (Moussard *et al*, 2017).
- as well as the British industrialist and cement manufacturer Joseph Aspdin (1778-1855), who obtained the patent for Portland cement in 1824 (Mascarenhas-Mateus, 2018).

In 1897, another significant contribution came from the French François de Hennebique with the use of iron bars and stirrups inserted in the mass of the concrete, which developed a construction system using the iron reinforced concrete that enabled the construction of spaces with spans of considerable size, and increased loads (Tostões, 2004).

Other variants of this product were developed in the early 20th-century like the pre-stressed concrete as well as the introduction of asbestos-cement. This process stemmed from the scientific progress that enabled the provision of different construction technologies coupled with experiences associated with the building of large manufacturing facilities, bridges, channels, garages, aerodromes, water storage tanks and as well as platforms, dams and power stations.

Already into the 20th century, leading contributions were made by the French engineer Eugène Freyssinet, who studied and determined its characteristics. He patented his ideas in 1928, and was a structural designer and bridge builder, lacked the teaching qualities necessary to communicate his ideas to other engineers (Dinges, 2009), (Camprubí, 2017).

Just like reinforced cement, pre-stressed concrete also incorporated steel but held a higher load capacity and thereby endowing greater resistance and durability to cement features and correspondingly broadening their scope of utilisation in civil construction.

In Portugal, the 1920s-1930s were years of experimentation and adaptation to the principles of Modern Architecture with the application of modern materials alongside the daring solutions that only engineers knew how to design (Tostões, 2004). The modern architecture movements would foster the awareness of the artistry and capacity of reinforced cement in following the works of Auguste Perret who encourages the use of reinforced concrete due to its potentialities to find new structural systems and aesthetic solutions (Tostões, 2004). However, materials such as reinforced cement would only enter in regular use in the 1950s. Until then only a limited group of engineers knows how to apply appropriately this material given its need for unusual calculations and application manuals (Appleton, 2004). This reality, more transversal to the entire civil construction sector, did not prevent the emergence of very particular experiences in the usage of Portland cement in as early as the 19th-century and the first decades of the following century. In Portugal, the first significant cement construction was the new building of Moagem do Carmujo [Caramujo Wheat Mill], built in 1898 (Toscano, 2012) and the Luiz Bandeira de Sejães Bridge on the EN333-3 over the river Vouga, dating to 1907, opening up a new paradigm in the history of construction. (Appleton, 2004). The choice of this material stemmed from the need to design industrial facilities structured into large pavilions, capable of bearing significant loads, providing stable structures and flooring simultaneously more resistant to fire and high temperatures.

With the proliferation of functional modernism backed by the ongoing calculations and research, the technical intelligence of the engineers ensured the architects recognized this new material for establishing a new aesthetic language using the plasticity of this material to project large openings with extensive glazing, creating a taste for smooth surfaces and pure volumes (Tostões, 2004). In this context, there stood out in Lisbon works such as the Portugália Brewery (1912-1914); the Capitólio cinema by Cristino da Silva (1896-1976) in 1929; the Instituto Superior Técnico, designed by Porfírio Pardal Monteiro in 1927 and completed in 1936. In Porto, these were accompanied by the São João Theatre (1910-1918), the Armazéns Nascimento Department Store (1914-1927) and the Garage for *O Comércio do Porto* newspaper designed by the architect Rogério Azevedo (1899-1983); the Passos Manuel Garage by the architect Mário Abreu; as well as the fish fridge building in Massarelos by Januário Godinho (Tostões, 2004).

The introduction of reinforced concrete in Portugal led to the publication, in 1918, of the Regulatory Instructions for the employment of Concrete, carried out based on the French norms and its later developments. (Appelton, 2004). A new regulation was published in 1935, establishing the need for rigorous calculations to meet the needs of compression, tension and safety of reinforced concrete works, among other aspects, demonstrating a broad field of applications of this material in civil construction (Decree 25.948 of October 16, 1935).

In parallel, the cement industry underwent significant expansion. According to Mascarenhas-Mateus studies “The effective production of natural cement began in 1866 under the Rasca brand manufactures in Alcântara, Lisboa, by Francisco Pereira de Gusman” (Mascarenhas-Mateus, 2018, p. 905), while the first industrial production unit had been founded in 1898, Companhia Cimento Tejo in Allandra by António Teóphilo Araújo Rato (Mascarenhas-Mateus, 2018). In the 20th-century, new facilities came in the 1920s, with Maceira-Liz factory in Leiria, which began operating in 1923,

and under the Estado Novo government was founded in 1930 the major corporate group: SECIL – Companhia Geral de Cal e Cimento S.A. In 1934, Lusalite began the elaboration of fiber-cement, being an associated company to the group Sommer that centralised the entire sector. This was the result of the protectionist and interventionist policy of Salazar's government since 1931, but the changes in the sector only began after World War II (Costa, Fazenda et al., 2010).

3. The teaching of engineering and the introduction of reinforced concrete

The introduction of this new material is associated with the reorganisation of engineering education, especially in civil engineering. Since 1881-82 the military School had a scientific approach, it became part of the curricula for the engineers' training. This new material was already disseminated in the 19th-century by the review «Le Betón Armé et ses Applications» published by Paul Christophe, engineer of Ponts et Chaussés School and in Portugal by the *Revista de Obras Públicas e Minas* 1870-1926, edited by Associação dos Engenheiros Civis Portugueses [Association of Portuguese Civil Engineers] (Mascarenhas-Mateus, 2018).

Under the Republic government, two schools were founded: the Lisbon Instituto Superior Técnico and the University of Porto. In the latter, the Technical Faculty was created in 1915 and was transformed, in 1926, into the Faculty of Engineering of the University of Porto.

The Technical Faculty of the University of Porto was one of the first schools officially to approve this discipline in the curricular plan. The school board decided in 1917 to recruit Francisco Xavier Esteves to be the professor of «Reinforced concrete and Bridges» (FEUP/Actas do Conselho Escolar, 1917). This teacher obtained a degree in civil engineering from the Politécnica Academy (Tavares, 2017), and in 1912 was a managing partner of the *Companhia de Cimentos Tejo*, using Portland cement. Among Xavier Esteves' works, *Livraria Lello* (bookshop Lello) stands out, a 1904 project where the cement is used in the interior stairs, in the gallery of the store and the frame of the facade. Xavier Esteves also signed other works like the 1898 Augusto Pereira Nobre's house [1] in the street of Castelo do Queijo (Foz do Douro) or Diogo Eugénio Cabral's residence[2] located on Rua Miguel Bombarda and which received works of expansion in 1927, using Portland cement (AHMP/CMP, L. O. nº192/1928). It is important to emphasise that in the case of the *Livraria Lello* the neo-gothic facade was built with the use of Portland Cement also due to its moulding capacities (Vale, 2012).

The active participation in public life led Xavier Esteves to embrace other projects and, in addition to his short experience in engineering education, he joined, from December 1917 to June 1918, Sidónio Pais' government, as Minister of Commerce (between December 11, 1917, and March 7, 1918) and Minister of Finance (between 7 March and 1 June 1918). Later, his business connections led him to be elected a second term as president of the Portuense Industrial Association, between 1919 and 1930.

From 1922 the chair of «Reinforced concrete» was taught by Theotónio Rodrigues, but in 1932 it became the responsibility of Antão Almeida Garrett, (1897-1978), recently graduated in civil engineering.

Graduated in 1925 by the University of Porto, he became professor-assistant of the First Group: Civil Constructions in the Faculty of Engineering of the University of Porto and recruited in 1932 to the chair of «Reinforced Concrete». According to the educational traditions prevailing in engineering schools, he produced an anthology that included the definitions and characteristics of this material, its usages as well as the formulas and calculations for building different structures and that remained an essential reference manual throughout many years. Students, also keeping the tradition, would annually produce new editions and we highlight the contributions of the re-edited manual by Pinto Basto and Lamas Viana, Alfredo Barata da Rocha, Alberto Fontes, Vicente de Paiva, Torquato Alvares Ribeiro and as well as the engineer Edgar Cardoso, who would also be a professor of engineering at *Instituto Superior Técnico*, founding in 1944 his own Laboratory for the Study of Structures and Foundations. Cardoso had extensive work with the use of concrete as well as other materials. Among his projects is the Arrábida Bridge in 1963 and the S. João Railway Bridge in Porto, opened in 1991.

Like reinforced concrete, pre-stressed concrete was also introduced in engineering education through the contacts and missions carried out by another professor of Porto University, Francisco Sarmento Correia de Araújo, who graduated in civil engineering in 1934. He carried out a mission financed by the Instituto de Alta Cultura at the Gent University (Belgium) where he worked with Gustaaf Robert Magnel, professor of reinforced concrete and founder of the Magnel Laboratory for Concrete Research one of the great centres of expertise and knowledge dissemination of reinforced and

1 Augusto Pereira Nobre (1865-1946) was a biologist and professor of Porto University.

2. Diogo Eugénio Cabral was a Porto industrialist and 1st Count of Vizela.

prestressed concrete in Europe. Gustave Magnel gave many lectures in several countries in which he explained in a simple way the principles of pre-stressed concrete and wrote the first book of design in this subject (Dinges, 2009).

This experience ensured Correia de Araújo to played a decisive role not only in teaching civil engineering but also in the dissemination the use of reinforced concrete, participating in the technical teams for diverse public projects that resulted in some of the emblematic landmarks of Porto city. His position as head of the Serviços de Obras Municipais e Habitações Populares (1940-41) [Town Constructions and Inhabitants Houses Department] enabled his interventions in the reinforced concrete project for the Massarelos Bolsa do Pescado [Massarelos Fishing Market]; the calculations for the Massarelos bridge to fish fridge; the inspection, the calculation of the projects of the construction of the "Abrigo dos Pequeninos" [Children Shelter]; the new City Council Hall, and the calculation and inspection of the construction of the Duque de Saldanha's local council housing project, among others.

Within the Porto Faculty of Engineering, the circulation of knowledge interlinked with the engineering practices of their professors but also extended to the missions financed by the Institute of High Culture (Instituto de Alta Cultura) that brought an increase of the technical intelligence able to apply and disseminate these new construction materials sustained by their respective calculations. There thus appeared new constructions held up by beams, pillars, roofing and terraces, large-scale architectural projects in their majority with high functional performance and resistance requirements. Dissemination and experimentation with these new materials were also much shaped by the founding of the Laboratory for Testing Construction Materials under the auspices of the Faculty of Engineering (established officially as a Cabinet of the school of engineering in 1915). The Faculty laboratory was used by the students in practical lessons and to do their projects, but also as outsourcing services for official and private entities, carried out a leading role in testing construction materials. This was where Professor Antão Almeida Garrett do experiments with different materials, especially national woods: maritime pine from Leiria, and reinforced concrete helicoid beams as well as testing the fire resistant properties of reinforced concrete, demonstrating that when slowly exposed to high temperatures it would inevitably get destroyed (Garrett, 1938). Many other tests and studies took place not only in conjunction with the academic programs but also as a result of studies requested from industry and official entities, with the laboratory taking on a determinant role in engineering research. Antão Almeida Garrett would take over as its director in 1964.

4. The artificial silk factory expansion plan: Company "Fibra Comercial Lusitana Lda."

From the 1920s, new construction projects of private entities in the city of Porto allowed for the emergence of works that marked the introduction of a modern architecture capable of designing the necessary interior functionality of the buildings. One of the industrial buildings that used reinforced concrete was the factory of the company "Fibra Commercial Lusitana Lda" — designed in 1933 by the architect Leandro de Morais (1883-?) in a parcel of land situated in the crossroad between the avenue of Boavista and the street Coutinho de Azevedo, neighbouring another textile unit: Fábrica de Fiação e Tecidos da Boavista owned by William Graham. This new unit was part of the group of industrial units located in this new avenue, an important expansion axis for the city towards the west allowing the connection of the city centre to the sea, in particular to Leixões Port, through the maritime marginal or crossing of the agricultural suburbs.

Three years after licensing the first building for the artificial silk (rayon) factory, the company advanced with an investment in its expansion through the addition of a perpendicular body, with a sizeable volumetric scale and careful design, surrounded by a garden that extended as far as the avenue.

The calculations for the concrete structures were of the responsibility of Antão Almeida Garrett who established the scale, loads and tensions for each construction component. The new building would form a typified example of modern architecture from the early 20th-century, with a regular composition and flat roofing surface. The imposing southern facade stands out in this otherwise classically designed building with its innovation emerging out of the scale of the vertical openings that only become feasible due to their reinforced concrete infrastructure. The flat roof with a terrace was lined by a row of sheds supported by concrete trusses. On the inside, space was divided by a concrete beam-pillar structure that replicated the design of the metallic structures that were previously applied to these buildings while ensuring a wide and very open space with a scalable to cope with the installation of heavy and large-scale machinery and equipment.

The Descriptive Memory of the project details not only the calculations as well as the description of the materials. In this document, the engineer Garrett presents the use of a reinforced concrete skeleton that supports the building from the first floor to the roof, showing all the calculations for beams, pillars, sheds and concludes by highlighting

the use of asbestos-cement in the roof (L.O. 1146/1936).

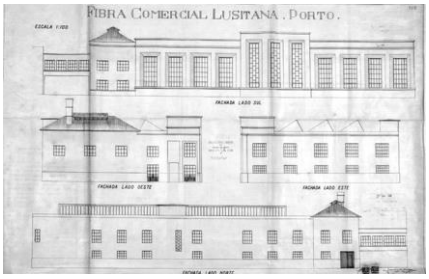

Fig. 1: Architectural project of the new building of the company *Fibra Comercial Luzitana, Lda*. 1936. Source: CMP / AHMP. L.O. nº 1146/ 1936, p. 416.

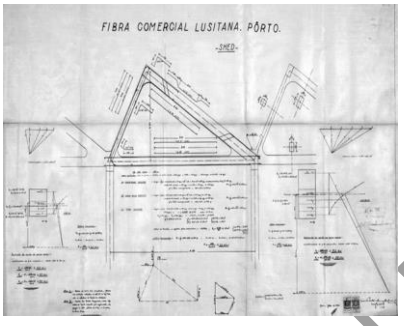

Fig. 2. Project of Shed coverage of the new building of the company *Fibra Comercial Luzitana, Lda*. 1936. Source: CMP / AHMP. L.O. nº 1146/ 1936, p. 426.

This new industrial building is another example of the complicity established between modern architecture and engineering, in a partnership irredeemable for the experimental load that the new constructive materials imposed.

Antão Almeida Garrett was involved in other projects. From 1930 and 1939 we found his signature in projects for water tanks, terraces, garages, bourgeois dwellings, alterations of buildings, using always reinforced concrete, namely for the coverings, pavements, pillars and beams.

5. Antão Almeida Garrett: reflections and experiences with reinforced concrete

Antão Almeida Garrett was engaged in the task of promoting and disseminating new construction materials and techniques and their impacts on the construction industry. In 1932, he wrote an article for the Bulletin of the Civil Engineers Association of Northern Portugal, entitled "Construction Processes", where he details a new process of using concrete in order to build walls that would enable homes to become more insulated from temperature variations (Garrett, 1932). Hence, this engineering professor, driven by his preference for reinforced concrete and his capacity for experimentation, set up an area to make concrete moulds at the bottom of his garden. His tests and studies led him to the production of a unique layout of moulds, resulting in a concrete beam with two support frames (Garrett, 1932). In 1938 he published "O betão armado e o fogo" [Reinforced Concrete and the Fire] and he related the experiences made in concrete, following the studies and fire tests of the American Professor I. H. Woolson and Professor M. M. Milankovitch from University of Belgrade, and also from the *Station d' Essais de L' Office National des Recherches et Inventions*, demonstrating to be aware of the works in this area in other universities and research centres.

The rationalisation of construction systems was also a strong subject for this engineer, and he defended the use of national raw materials for civil construction. He published an article, in 1939, in the University of Porto Engineering Journal entitled "Porque se não deverá empregar tanto betão armado" [Why we should not employ so much reinforced concrete] In the opening lines, he answered by saying that iron is imported; it is applied where there is no justification, and also because reinforced concrete is generally poorly designed and badly executed (Garrett, 1939).

The article continues with a set of considerations against the high costs of iron imports for reinforced concrete, declaring his opposition to the incorrect employment of reinforced concrete. In parallel, he thus defended the use of national woods, referring to how such materials hold the capacities to provide solutions to the different demands of construction systems. Garrett ends his reflections by expressing the idea that technical progress in this field does' not yet have given a substantial improvement on civil construction (Garrett, 1939).

We highlight that the introduction of concrete was a gradual process and with Estado Novo regime (1926-1974) started the regulation and control of the process of civil construction and housing projects, framed within the urban growth projects of the main urban centres.

Antão Almeida Garrett had a long career as professor and engineer, and from the 1940s, he undertook numerous studies, focusing in particular in the urban plan of Porto, working in partnership with national and foreign architects and urban planners.

6. Conclusion

The first uses of reinforced concrete demonstrate a progressive knowledge of the properties of new materials for civil construction, but their diffusion

was also due to engineering schools and its teachers. They have a privileged role in the circulation of technical knowledge, the diffusion of new practices and the use of new building materials.

The first generations of graduated engineers from the Faculdade Técnica of the University of Porto, played an essential role in the dissemination of this knowledge, especially Antão Almeida Garrett, who throughout his career as professor improved the technical intelligence in his disciples and as engineer designed small-scale projects such as concrete structures for water tanks, terraces, but also projects of concrete structures for factory buildings, houses, making extensive use of reinforced concrete and even asbestos-cement.

Antão Almeida Garrett fostered the study of new materials, especially the reinforced concrete with his experimentation and theoretical principles improving the modernisation of the civil construction, sustained by the development of engineering.

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