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SILOS. Paesaggi dell'abbondanza, depositi di memorie

SILOS. Landscapes of plenty, repositories of memories

A cura di
Roberto Parisi

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Indice

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Territori al lavoro

Biblioteca

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Manuals, journals, patents: development and international circulation of technical-constructive solutions for grain silos between the 19th and 20th centuries

Manuali, riviste, brevetti: sviluppo e circolazione internazionale delle soluzioni tecnico-costruttive per i silos granari fra il XIX e il XX secolo

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ABSTRACT

The grain silos typology first appeared during the second half of the 19th century in the United States. Since then, different construction techniques were experimented to ensure a higher fire resistance and structural strength. The exchange of knowledge between America and Europe, concerning the design and construction of this building typology, is a topic of great interest, but not yet duly investigated. For this reason, the present study aims to bring attention to it, starting with a focus on a crucial phase in the construction history, characterised by unprecedented advances: the period that goes from the last decade of the 19th century to the first two decades of the 20th century. In particular, the study will investigate the role in the development of the grain silo typology played by the US and German designers and builders, starting from the analysis of the manuals and journals which represented a major vehicle for the transmission of technical knowledge and patents.

KEYWORDS

Construction history
Grain silos
Manuals
Journals
Patents

Introduction

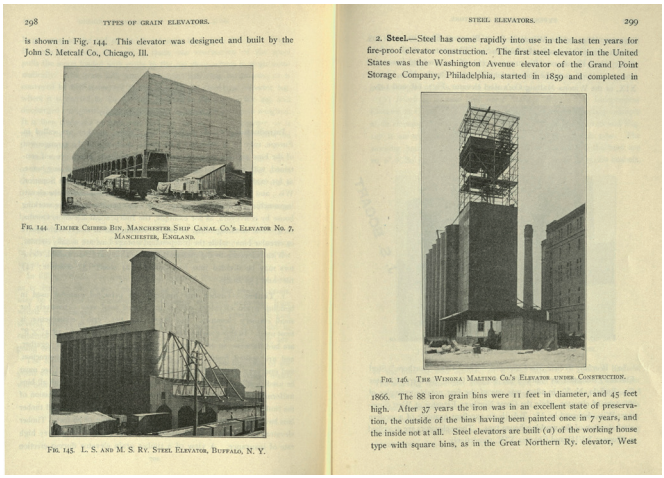
> *Les bétons agglomérés, par leur imperméabilité, par leur monolithisme, donneraient encore la solution d'un problème dont l'importance s'étend à la société tout entière; il donnerait enfin le moyen de faire des silos complètement propres à la conservation durable de toutes les céréales, et même des vins et des huiles; application dont les conséquences sociales, pour la salubrité, le bien-être des populations, la sûreté de l'État, dépassent par leur importance les conditions d'une simple réforme dans l'art de construire. Il n'y a pas lieu de s'étendre sur ce sujet; il suffit de l'indiquer et de dire que des silos en béton aggloméré ne coûteraient pas un franc pour la capacité d'un hectolitre, tandis que, par les seuls moyens préconisés jusqu'à ce jour, ils coûteraient au moins quatre à cinq fois plus cher*[1].

With these words, the French entrepreneur François Coignet, in his text from 1861 *Des bétons agglomérés appliqués à l'art de construire* proposed – or rather, foresaw – the use of reinforced concrete for the construction of silos for the long-term storage of grain, even if a few more decades would have actually had to pass before reinforced concrete was experimented for the construction of grain silos, both in the European and American contexts.

The grain elevator typology first appeared during the second half of the 19th century in the United States. The invention of the elevator mechanism is attributed to Oliver Evans, who developed, during the 1780s, a gravity-fed mill characterized by a bucket conveyor aimed to raise the grain to the top of the mill, whence it could flow down thanks to its own weight[2]. The introduction of the grain elevator as a building typology, instead, is commonly attributed to the merchant Joseph Dart from Buffalo, even if, according to further hypothesis, Dart simply has the merit of having paid for the construction of the first grain elevator, while it was conceived actually, and then built, by Robert Dunbar and his team between November 1842 and May 1843[3]. Since then, different construction techniques were employed to ensure greater fire resistance of grain silos (fires being frequent) and greater structural strength (not only for static loading, but especially during the filling and emptying phases) meant that many different materials were gradually experimented, from traditional materials, such as brick and wood, to modern materials, such as steel and concrete, either in the form of prefabricated blocks or cast-in-place reinforced concrete.
The dynamics that allowed the exchange of knowledge and skills for the construction of grain silos between Europe and America is a topic of great interest, and not yet duly investigated. For this reason, this contribution intends to bring attention to it, starting by outlining the ways and means by which this exchange took place. The period of analysis goes from the last decade of the 19th century to the first two decades of the 20th century: a period characterised by remarkable advances in the field of construction science and technology, from both a theoretical and practical point of view. The present study aims to investigate, in particular, the role of the United States and Germany, with their engineers, architects and builders, in the development of the grain silo typology, starting with the analysis of the manuals and journals which represented a major vehicle for the transmission, at the national and international scale, of technical solutions and patents. For this reason, the research is strongly related to the wider framework of studies on the patents developed since the 19th century, concerning the development of machinery for the agri-food industry, as well as construction systems and prefabricated building components[4].

The North American context

As for the North American context, it is necessary to refer first to the manual[5] published by Professor Milo Smith Ketchum, dean of the College of Engineering at the University of Colorado[6], who wrote extensively about the design of grain silos and mills, as well as about infrastructure works and industrial buildings. Among his books[7], published by McGraw-Hill, we find a manual of particular interest, entitled "Design of Walls, Bins and Grain Elevators" (first edition 1907, second edition 1911), which showcases a large number of examples, including detailed descriptions, mathematical calculations, technical drawings of plans, sections and details, together with photos of grain silos under construction and completed, deemed useful for the readers to understand the silos construction process in depth and, of course, incredibly valuable to the present research.
In the introduction, the manual gets straight to the point of the problem it purposes to address, including the issue of the granular fluid's behaviour of grain. We can say, indeed, that grain acts both as a solid and as a fluid – it can be stocked in conical piles because of its internal friction but, when its internal friction angle is exceeded, it can flow like water. The storage of such a product requires an understanding of internal pressures – both vertical and outward – exerted on the container walls, by defining a mathematical model that accurately describes existing forces, materials used and shapes required.
The selection of examples by Prof. Ketchum is of particular interest (including both built examples and patents, representative of various construction techniques), as well as the choice of figures, a rich set of technical drawings and photographs, included to complement the descriptions and calculation models.
The Introduction to "Parts III. The design of grain bins and elevators" includes the following grain elevators: 1) Manchester Ship Canal Co.'s Elevator No. 7, Manchester, England, built by John S. Metcalf Co.; 2) L.S. and M.S. Ry. Steel Elevator, Buffalo, New York; 3) Winona Malting Co.'s Elevator, Winona, Minnesota; 4) Missouri Pacific Ry.



298 TYPES OF GRAIN ELEVATORS.

is shown in Fig. 144. This elevator was designed and built by the John S. Metcalf Co., Chicago, Ill.

FIG. 144. TIMBER CRIBBED BIN, MANCHESTER SHIP CANAL CO.'S ELEVATOR NO. 7, MANCHESTER, ENGLAND.

FIG. 145. L. S. AND M. S. RY. STEEL ELEVATOR, BUFFALO, N. Y.

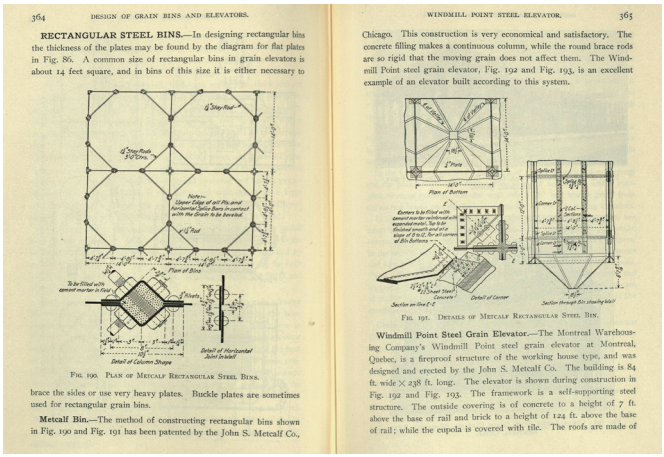
STEEL ELEVATORS. 299

2. **Steel.**—Steel has come rapidly into use in the last ten years for fire-proof elevator construction. The first steel elevator in the United States was the Washington Avenue elevator of the Grand Point Storage Company, Philadelphia, started in 1859 and completed in

FIG. 146. THE WINONA MALTING CO.'S ELEVATOR UNDER CONSTRUCTION.

1866. The 88 iron grain bins were 11 feet in diameter, and 45 feet high. After 37 years the iron was in an excellent state of preservation, the outside of the bins having been painted once in 7 years, and the inside not at all. Steel elevators are built (*a*) of the working house type with square bins, as in the Great Northern Ry. elevator, West

1. Manchester Ship Canal Co.'s Elevator No. 7 (Source: Ketchum, 1907).



364 DESIGN OF GRAIN BINS AND ELEVATORS.

RECTANGULAR STEEL BINS.—In designing rectangular bins the thickness of the plates may be found by the diagram for flat plates in Fig. 86. A common size of rectangular bins in grain elevators is about 14 feet square, and in bins of this size it is either necessary to

FIG. 190. PLAN OF METCALF RECTANGULAR STEEL BINS.

brace the sides or use very heavy plates. Buckle plates are sometimes used for rectangular grain bins.

Metcalf Bin.—The method of constructing rectangular bins shown in Fig. 190 and Fig. 191 has been patented by the John S. Metcalf Co.,

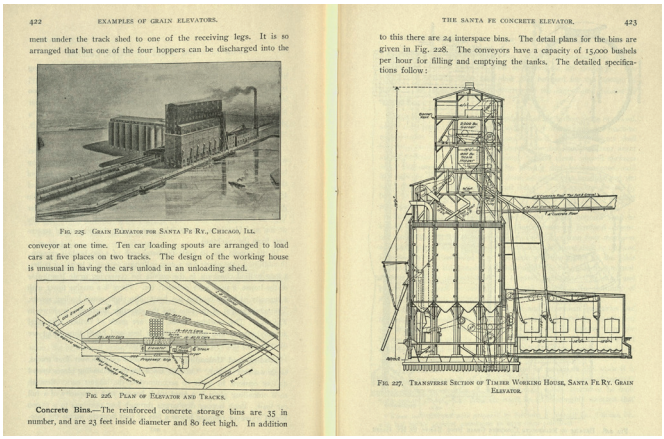
WINDMILL POINT STEEL ELEVATOR. 365

Chicago. This construction is very economical and satisfactory. The concrete filling makes a continuous column, while the round brace rods are so rigid that the moving grain does not affect them. The Windmill Point steel grain elevator, Fig. 192 and Fig. 193, is an excellent example of an elevator built according to this system.

FIG. 191. DETAILS OF METCALF RECTANGULAR STEEL BIN.

Windmill Point Steel Grain Elevator.—The Montreal Warehousing Company's Windmill Point steel grain elevator at Montreal, Quebec, is a fireproof structure of the working house type, and was designed and erected by the John S. Metcalf Co. The building is 84 ft. wide × 238 ft. long. The elevator is shown during construction in Fig. 192 and Fig. 193. The framework is a self-supporting steel structure. The outside covering is of concrete to a height of 7 ft. above the base of rail and brick to a height of 124 ft. above the base of rail; while the cupola is covered with tile. The roofs are made of

2. Patent of rectangular Steel Bins designed by J. Metcalf (Source: Ketchum, 1907).



422 EXAMPLES OF GRAIN ELEVATORS.

ment under the track shed to one of the receiving legs. It is so arranged that but one of the four hoppers can be discharged into the

FIG. 225. GRAIN ELEVATOR FOR SANTA FE RY., CHICAGO, ILL.

conveyor at one time. Ten car loading spouts are arranged to load cars at five places on two tracks. The design of the working house is unusual in having the cars unload in an unloading shed.

FIG. 226. PLAN OF ELEVATOR AND TRACKS.

Concrete Bins.—The reinforced concrete storage bins are 35 in number, and are 23 feet inside diameter and 80 feet high. In addition

THE SANTA FE CONCRETE ELEVATOR. 423

to this there are 24 interspace bins. The detail plans for the bins are given in Fig. 228. The conveyors have a capacity of 15,000 bushels per hour for filling and emptying the tanks. The detailed specifications follow:

FIG. 227. TRANSVERSE SECTION OF TIMBER WORKING HOUSE, SANTA FE RY. GRAIN ELEVATOR.

3. Grain Elevator for Santa Fe Ry Chicago (Source: Ketchum, 1907).

Co.'s reinforced concrete elevator, Kansas City, Missouri; 5) Patent of reinforced concrete grain elevator with squared bins designed by J. A. Jamieson; 6) Tile grain bins during construction (elevator not identified by the company's name nor the location).
The description of these examples is followed by a comparative analysis of the different solutions, that is preliminary to the in-depth examination, in Chapter XVIII of Part III, of further case studies (listed below in the same order in as they appear in the manual): 1) Manhattan Malting Co. steel elevator, Manhattan, Montana; 2) Patent of rectangular Steel Bins designed by J.S. Metcalf; 3) Grand trunk steel grain elevator, Windmill Point, Montreal, Quebec; 4) Patent of circular bin designed by J. MacDonald; 5) C.H. & D. Elevator "B" Toledo, designed by J. MacDonald; 6) Steel Grain Elevator constructed on Macdonald System [no location indicated]; 7) Great Northern Steel Elevator, Buffalo, New York; 8) Missouri Pacific Ry. Concrete grain bins; 9) Patent of Tile grain bin by Barnett-Record; 10) Patent of Tile grain bin by Witherspoon-Englar; 11) Fisher Flouring Mills [no location indicated].
Then, a further series of elevators is showcased, each with numerous detailed drawings, in "Chapter XIX. Examples of Grain Elevators": 1) Independent Elevator, Omaha, Nebraska; 2) Grain Elevator for great Northern Ry., at West Superior, Wisconsin; 3) Grain Elevator for Santa Fe Ry., Chicago, Illinois; 4) Canadian Pacific grain elevator, Porth Arthur, Ontario; 5) Grain Elevator for Canadian Northern Railway, Port Arthur, Ontario [original elevator B]; 6) Storage annex with circular bins to the Steel Grain Elevator, Great Northern Ry., West Superior, Wisconsin; 7) Grand Trunk Pacific Ry. concrete grain elevator, Fort Williams, Ontario; 8) F.C. Ayres mercantile Co. grain elevator, Denver, Colorado.
Therefore, a total of 24 examples are described, including 19 built silos and 5 patents. From the geographical point of view, only one example falls out of North American context, the Manchester Ship Canal Co.'s Elevator No. 7, which anyway was built by John S. Metcalf Co. based in Chicago.
The research focus was then turned to specialised journals in the North American context. Among these, the monthly journal entitled 'The American Elevator and Grain Trade', published on the 15th of every month starting in July 1896, proved to be the most extensive and specialised source on grain elevators in the area. This journal was intended to collect every king of information related to the grain trade in America, from prices, regulations, institutions, and subjects involved (including satirical cartoons around them!) and, of course, to the grain elevators and its mechanical components.
The first pages of the journal are always dedicated to newly built exemplary grain silos. Just as examples, we recall the issue of 15 November 1906[8], which reports the construction of the Santa Fe Railroad Elevator on Chicago River, with plans and specifications by John S. Metcalf Co., Chicago; construction by the MacDonald Engineering Co., Chicago. The issue dated 15 January 1914[9], reports both the construction of the New Concrete Storage Tanks of the Quaker Oats Company, Cedar Rapids, Iowa, designed and built by the Stephens Engineering Company, Chicago, and the construction of the Lehigh Valley Railroad Terminal Elevator at Jersey City, designed and constructed by the Witherspoon-Englar Company, Chicago.
Particularly interesting for the present study is the section of this journal entitled 'Late patents', which mainly concerns the development of new mechanical equipment: an indication that innovation and developments were even more intense on that side than on constructive solutions. Quite significant are also the pages devoted to advertisements of construction companies specialised in the design and construction of grain elevators, such as: MacDonald Engineering Co., Witherspoon-Englar Co., John S. Metcalf Co., Barnett & Record Co., Witherspoon-Englar Co. (all of them using the respective above-mentioned patents), JamesStewart &Co., G.T. Honstain, Riter-Conley Mfg. Co., Burrell Engineering & Construction Co., Barnard & Leas Mfg. Co., W. S. Cleveland & Co., Minneapolis Steel & Machinery Co., and many others.
Quite interesting, especially to understand which types of silos were gradually becoming obsolete, is the section reporting grain elevators for sale and for rent, as well as the pages dedicated to fires and collapses, which continually affected these buildings (attesting that, despite the contiuous search for fireproof constructive solutions, this typology, at least for the first decades of its development, was not exempt).
In the newspaper, there are also references (although not very frequent) to the international reality, from various points of view. The issue of 15 August 1896[10], for example, contains a short article on 'European marine legs' (page 50), which, the article says,

4. Advertising (Source: The American elevator and grain trade,15 November 1906, pp. 54-55).

5. Map of grain silos mentioned in the US (Source: Dati cartografici @2023 Google, INEGI).

"differ little in principle from the American, after which they are copied, and contrary to what would be expected they are not heavier and more cumbersome to handle". The issue of 15 June 1904[11] applauds Mexico's decision to equip the country with grain elevators for better grain handling and trade. Of considerable interest is the issue of 15 January 1919[12], which applauds Australia's efforts to start building modern grain elevators but, above all, it provides updates on food supply in Europe in consideration of the dramatic conditions following World War I, with two articles[13] and a satirical cartoon[14].

The German context

As already pointed out by several authors, first and foremost the architectural historian Reyner Banham[15], the American grain elevators entered the European collective imaginary as iconic references in the development of the modern architectural language. This followed the dissemination of several photographs of American grain elevators by Walter Gropius[16] and others: a reiteration of images, in some cases even modified ad hoc, through public lectures, exhibitions, articles and books, the purpose of which was to convey an idea of monumentality, purity of volumes and shapes that were to become cardinal principles of the new architectural language[17].
An interesting study on these set of photographs, centred on the issue of their trade, particularly in Germany, was conducted by Catalina Mejía Moreno. This brings us to reflect on how, in this case, the history of architecture, and in particular the development of modern architectural language, is intertwined with the history of engineering and constructions not in the most direct way we are used to thinking about it, that is: new materials and construction systems allowed new shapes and formal solutions.

What happens here is that new engineering structures, the grain elevators, deprived of their technological and functional aspects, are proposed as iconic objects exemplary of specific morphological features. In fact, many of these photos, taken from specialized journals and construction manuals (as firstly observed by Nerdinger and then, by Mejía Moreno), were disengaged, by Gropius first, from their technical descriptions, calculations, details, patents, construction companies, which were essential in conveying the whole design and construction process. By using these pictures in his lecture in Hagen, in April 1911, and in the 1913 Werkbund yearbook, Gropius final aim seems to be making the grain elevators "a 'discovery' made by the architect rather than a reference to someone else's work"[18].

During the early 20th century, the exchange and trade of photographs was a common practice in Germany. Gropius, while working for Peter Behrens in Berlin, began collecting a large number of photographs of American and German grain elevators from many different sources. This set of images served several purposes within Behrens's office, such as being a resource for technical details.

Despite some authors[19] suggested that the grain elevators' photos were sent to Gropius from the US, it is also possible that they came from local printed sources. Nerdinger[20] was the first to acknowledge that two of the photographs showed during Gropius's lecture in 1911 and published in the 1913 yearbook were taken from "Beton und Eisen" [Concrete and Iron], one of the many German concrete journals published at the time.

Mejía Moreno research offered further evidence for this hypothesis, identifying examples of elevators used by Gropius previously published in different journals: an issue of the journal "Zement und Beton"[21] [Cement and Concrete] published in 1908 about a corn silo in Minneapolis; an article published in "Beton und Eisen"[22] from 1909, showing an elevator built in Baltimore; an article published in Eisenbeton[23] [Ferroconcrete] in 1909, whose location, moreover, is incorrectly reported by Gropius; and finally, an article in "Beton und Eisen"[24] from 1910, about a corn silo in Buenos Aires.

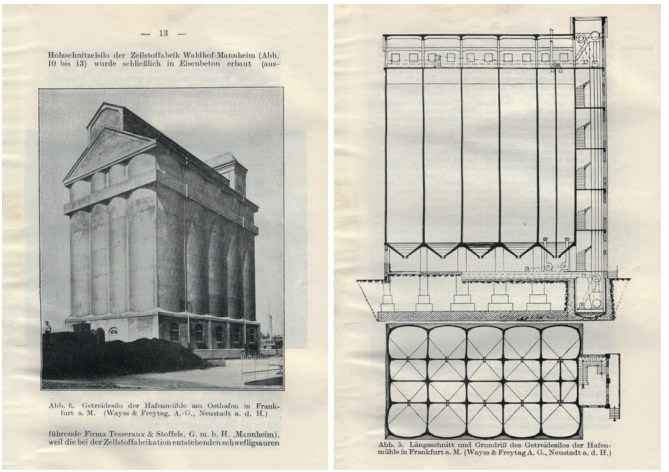
A further important source in the above-mentioned journals, as seen in the American specialist journals, are the advertisements of construction companies specialised in the design and construction of grain elevators, reproducing the most important works built by the same companies. As good example is the promotional brochure produced by Wayss und Freytag, showing a grain Silo in Worms[25].

Thus, Mejía Moreno, by referring to the many German journals, provides valuable information on those channels for the exchange of technical constructive knowledge between Europe and America that this contribution seeks to explore. The search starting from this "track" led to the identification of the volume 'Silobauten in Beton und Eisenbeton' from 1914, entirely dedicated to the design of reinforced concrete silos for grain, cement and coal. Each example is described with plan and section drawings, photos of the silos under construction and photos of the silos completed. We observe that, compared to Ketchum's manual, the calculation part and the construction details are missing, thus this publication doesn't absolve the same task of a construction manual.

As for the typology of silos for cereals, it reports the following cases: 1) Grain silo of the harbour mill in Frankfurt am Main, Germany (Wayss & Freytag A.G.); 2) Grain silo of Leysieffer & Lietzmann in Cöln-Deutz, Germany (W. Gärtner & Co, Cöln a. Rh.); 3) Grain silo in Castellamare, Italy (Wayss & Freytag A. G.); 4) Malt silo of the Eisenberg brewery in Erfurt, Germany (Wayss & Freytag A.G.); 5) Grain Silo in Banteln, Germany (B. Liebold & Co. A.G., Holzminden). The manufacturing companies specified in brackets are those listed in the image captions of the cited volume. it should therefore be pointed out that it is left to later stages of research to investigate the specific patents used in the various examples, in order to critically examine what is reported in the publication.

In terms of construction technology and typology, these are all examples of reinforced concrete silos with rectangular bins, except for the silo in Castellamare, which shows circular cells, and the silos in Frankfurt am Main, which has rectangular bins in the two central rows while the lateral bins show an atypical shape, with the exterior sides having a curvilinear shape, which is quite an interesting choice since the curvilinear shape for the perimeter walls ensures the best structural behaviour, while the rectangular shape inside allow to avoid the creation of rhomboidal interstitial bins.

While this research will be extended to include the analysis of other German journals and manuals on reinforced concrete construction, it is useful to anticipate in this contribution the key role played by the Wayss & Freytag A. G. company in the construction of



— 13 —

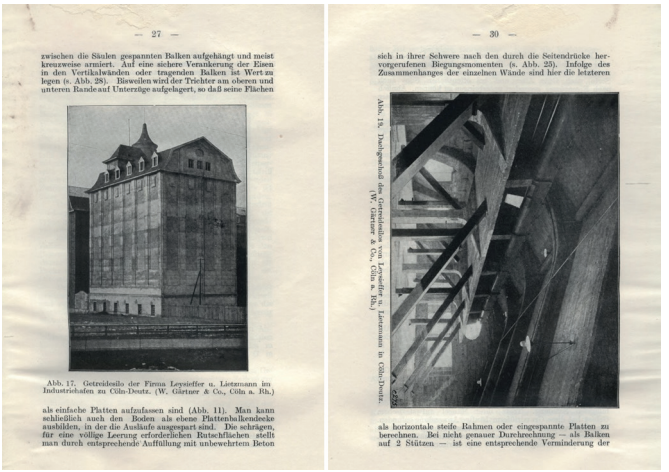
Holzschnitzelsilo der Zellstoffabrik Waldhof-Mannheim (Abb. 10 bis 13) wurde schließlich in Eisenbeton erbaut (aus-

Abb. 6. Getreidesilo der Hafenmühle am OstHafen in Frankfurt a. M. (Wayss & Freytag, A.-G., Neustadt a. d. H.)

führende Firma Tesseraux & Stoffels, G. m. b. H., Mannheim), weil die bei der Zellstoffabrikation entstehenden schwefligsauren

Abb. 5. Längsschnitt und Grundriß des Getreidesilos der Hafenmühle in Frankfurt a. M. (Wayss & Freytag A. G., Neustadt a. d. H.)

6. Grain silo of the harbour mill in Frankfurt am Main, Germany (Source: Silobauten in Beton und Eisenbeton, 1914, pp.14-15).



— 27 —

zwischen die Säulen gespannten Balken aufgehängt und meist kreuzweise armiert. Auf eine sichere Verankerung der Eisen in den Vertikalwänden oder tragenden Balken ist Wert zu legen (s. Abb. 28). Bisweilen wird der Trichter am oberen und unteren Rande auf Unterzüge aufgelagert, so daß seine Flächen

Abb. 17. Getreidesilo der Firma Leysieffer u. Lietzmann im Industriehafen zu Cöln-Deutz. (W. Gärtner & Co., Cöln a. Rh.)

als einfache Platten aufzufassen sind (Abb. 11). Man kann schließlich auch den Boden als ebene Plattenbalkendecke ausbilden, in der die Ausläufe ausgespart sind. Die schrägen, für eine völlige Leerung erforderlichen Entschlüsse stellt man durch entsprechende Auffüllung mit unbewehrtem Beton

— 30 —

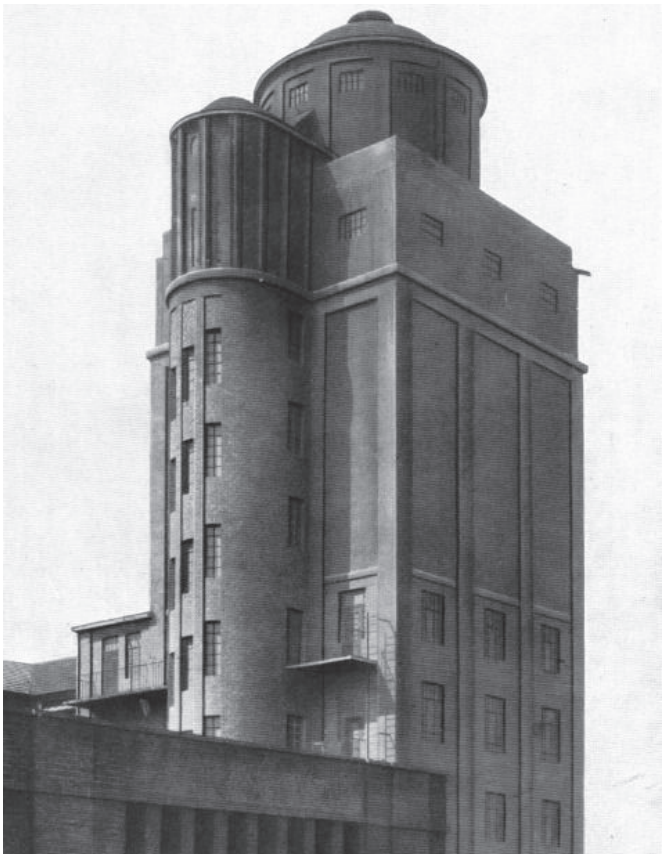
sich in ihrer Schwere nach den durch die Seitendrücke hervorgerufenen Biegungsmomenten (s. Abb. 25). Infolge des Zusammenhanges der einzelnen Wände sind hier die letzteren

Abb. 18. Dachgeschoß der Getreidesilos der Firma Leysieffer u. Lietzmann in Cöln-Deutz. (W. Gärtner & Co., Cöln a. Rh.)

als horizontale steife Rahmen oder eingespannte Platten zu berechnen. Bei nicht genauer Durchrechnung — als Balken auf 2 Stützen — ist eine entsprechende Verminderung der

7. Grain silo of Leysieffer & Lietzmann in Cöln-Deutz, Germany (Source: Silobauten in Beton und Eisenbeton, 1914, pp.27-30).

grain silos in Germany. The company, which appears as the builder of three of the five examples cited in the above-mentioned issue, was founded by Conrad Freytag, a German entrepreneur who acquired the Monier's patents for southern Germany in 1884, with rights of first refusal for northern Germany. In 1885, he transferred the right of first refusal for northern Germany free of charge to Gustav Adolf Wayss, who used and further developed the technique. As there was a lack of reliable knowledge about the interaction between iron and concrete, Wayss started an extensive test programme. The company ordered extensive experiments at the Technical University of Stuttgart, to deepen the knowledge of the elastic characteristics of steel and concrete. The scientific research into reinforced concrete construction was developed by engineer Emil Mörsch who, in 1908, took over the technical management of the Wayss & Freytag company. The three personalities of Freytag, Wayss and Mörsch contributing to the growth of the Wayss & Freytag company both at the national and international level[26]. The author's research for further grain silos constructed by Wayss & Freitag led to the discovery of another one in Ludwigshafen am Rhein from 1914 which, perhaps because it was constructed at the same time or shortly after, is not included in the aforementioned publication.
It should be noted that the silos included in the above-mentioned volume from 1914 are not as huge as the American examples, indicating a greater spread of small to me-



8. Grain silos in Ludwigshafen am Rhein, Germany.

dium-sized silos, which is a hypothesis that still remains to be verified. Nevertheless, there is no shortage of cases of large silos even in Europe, think of the grain silos in the port of Genoa, built between 1899 and 1901 by the G.A. Porcheddu company according to the Hennebique patents, and the grain silos in the port of Naples built during the mid-1910s and designed by the engineer Cristoforo Bozano[27], according to the Hennebique patents as well. It is worth mentioning that, at the turn of the 20th century, the Hennebique company, founded in 1892 in Bruxelles, played a leading role in the construction of reinforced concrete structures worldwide, thanks to its huge and dense network of agents and dealers, which represents a quite significant experience in the history of concrete construction. Among their works, we find a lot of grain silos, realized in Spain and Italy especially, but also in Portugal, Greece, Swilzerland, Germany, Denmark, UK, Russia, USA, Argentina and Chile[28].
Therefore, it seems quite strange that the Hennebique patents for grain silos do not find a space in publications outside of the company's official magazine, as shown by the American and German print sources analysed. But it would certainly need further investigation to understand whether this is indeed the case, and if so, what the reasons are.

Conclusions

What emerges from this first picture of the international exchange of knowledge for the construction of grain silos, deepened here considering North America and Germany between the 1890s and the 1910s, is that of a one-way exchange path, with German en-

9. Map of grain silos mentioned in the Europe (Source: Dati cartografici @2023 Google, GeoBasics-DE-BKG@2009, Inst. geogr. Nacional, Mapa GISrael).

gineers looking to American designers, and not vice versa, and with a specific focus on reinforced concrete grain silos, and not patents involving other building materials. In parallel, we have to keep in mind the superpower of the French Hennebique company, which builds in the same years dozens and dozens of grain silos in Europe and around the world. However, we should, above all, consider the in this period we assist to the beginning of the development of modern architecture, which intersects and proceeds with the development of the construction industry, sometimes directly, sometimes indirectly and controversially.

Many questions remain open and, therefore, possible avenues for future research development can be identified: what influences and exchanges of technical knowledge are there internally between European countries in the same period of analysis? And what about the European exchanges with South America and Russia? Then, shifting to the 1920s and 1930s, what role do the totalitarian regimes established in Europe play in this knowledge exchange? When where and why the experimentation of constructive solutions for grain silos combined with the search for a formal language for this utilitarian structures?

These are all intriguing questions, considering that the efficiency of granary silos meant the proper preservation of the primary product necessary for the subsistence of the population. And finally: how have these buildings stood the test of time? What is their current condition and use?

The analysis of these buildings offers, therefore, the opportunity to connect elements from the history of construction, history of technology, economic history, and political history, allowing a wide-ranging view of this building typology that was created to store grain: a cross-sectoral knowledge that is essential to understand their multiple values as a basis for their preservation as a historical and cultural heritage.

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[1] François Coignet, *Des bétons agglomérés appliqués à l'art de construire: mémoire adressé à la commission des arts insalubres de l'Académie des sciences, pour concourir au prix Monthyon*, G. Jousset, Paris 1861. English translation by the author: The impermeability and monolithic nature of agglomerated concrete would also provide the solution to a problem whose importance extends to society as a whole; it would finally provide the means of making silos completely suitable for the long-term conservation of all cereals, and even wines and oils; an application whose social consequences, for the health and well-being of populations and the security of the State, exceed in their importance the conditions of a simple reform in the art of construction. There is no need to dwell on this subject; it is sufficient to mention it and to say that agglomerated concrete silos would not cost a single franc for the capacity of a hectolitre, whereas, using the methods recommended to date, they would cost at least four or five times as much.

[2] Eugene S. Ferguson, *Oliver Evans: Inventive Genius of the American Industrial Revolution*. Eleutherian Mills-Hagley Foundation, Wilmington 1980; Oliver Evans, *The young mill-wright & miller's guide*, Philadelphia 1795.

[3] William J. Brown, *American Colossus: The Grain Elevator, 1843 to 1943*. Colossal Books, New York 2009.

[4] For further references concerning patents for the agri-food industry in Italy, see: Antonio Monte, *Brevetti e macchine per la produzione dell'industria alimentare*, in «Patrimonio Industriale», n. 21, 2019, pp. 28-47. Edoardo Currà, *Industrie per l'industria*, Editoriale in «Patrimonio Industriale», n. 21, 2019, pp. 6-8.

For further references concerning patents for construction systems and prefabricated building components in Italy see the publications by Tullia Iori and Sergio Poretti on Ferroconcrete by Pierluigi Nervi, the volume by Riccardo Nelva and Bruno Signorelli on the Hennebique's patents, the publications by Alberto Bologna on Danti Bini's concrete shells.

[5] Milo Smith Ketchum, *Design of Walls, Bins and Grain Elevators*, McGraw-Hill, 1907.

[6] Milo Smith Ketchum Jr., *Milo Smith Ketchum - dean, 1904 -1919*, talk delivered at the 100th Anniversary of the Department of Civil Engineering, University of Colorado, da https://www.ketchum.org/-milo/msksr.html (ultima consultazione: 27 maggio 2023).

[7] *The Design of Steel Mill Buildings and the Calculation of Stresses in Framed Structures, 1903; Design of Highway Bridges of Steel, Timber, and Concrete, 1908; Design of Mine Structures, 1912; Structural Engineers Handbook, 1914.*

[8] *The New Santa Fe elevator at Chicago*, Ill. in «The American Elevator and Grain Trade», 15 November 1906, p. 233.

[9] *Quaker Oats Plant Increases Storage Facilities*, in «The American Elevator and Grain Trade», 15 January 1914, p. 371.

[10] *European marine legs*, in «The American Elevator and Grain Trade», 15 August 1896, p. 50.

[11] *Elevators in Mexico*, in «The American Elevator and Grain Trade», 15 June 1904, p. 658.

[12] *Housing the Grain Crops of Australia*, in «The American Elevator and Grain Trade», 15 January 1919, p. 499.

[13] *Control of the Grain Trade in War Time. Measures Adopted by All Countries to Insure a Supply of Food During the Truing Years of war*, in «The American Elevator and Grain Trade», 15 January 1919, p. 500.
Feeding Europe's Hungry, in «The American Elevator and Grain Trade», 15 January 1919, p. 520.

[14] *New world - Old world*, in «The American Elevator and Grain Trade», 15 January 1919, p. 511. Original source: Leslie's Weekly, 4 January 1919.

[15] Reyner Banham, *A Concrete Atlantis. U.S Industrial Building and European Modern Architecture 1900-1925*, The MIT Press, Cambridge (MA) 1986.

[16] Walter Gropius, *Die Entwicklung moderner Industriebaukunst*, in «Die Kunst in Industrie und Handel Jahrbuch Des Deutschen Werkbundes 1913», Eugen Diederichs, Jena 1913.

[17] In Europe, the impact of Gropius's article was immediate, as shown by the work of Mario Chiattone, Antonio Sant'Elia and by the *Manifesto of Futuristic Architecture* (1914) and it was even more evident in the imaginary architectures sketched by Erich Mendelsohn (even before his visit to Buffalo, which would take place in 1924 and whose pictures are included in his book *Amerika: Bilderbuch eines Architekten*). Le Corbusier, in 1919, asked Gropius to lend him the images he had used in the article to include them in the magazine Esprit Noveau and later, in 1923, in his most renowned volume *Vers une Architecture*. Meanwhile, in the Soviet Union, in the context of the Russian Constructivism, there are numerous references to industrial architecture and grain elevators. They range from the geometries of the headquarters of Arkos in Moscow designed by A.I. Gueguello (1924), to the plastic studies in the Art school of Leningrad, to the Moscatov silos (1929) by Lisstizky. The most significant contribution from this point of view, however, is probably the work of Yakov Chernikov, and his formal speculations on imaginary architectures.

[18] Catalina Mejía Moreno, Photographs of Silos: On the Contingency of a Modern Photographic Canon, in "Architectural Histories", 10(1): 5, 2022, pp. 1–30.

[19] Gerda Breuer, Annemarie Jaeggi (eds), *Walter Gropius: Amerikareise 1928*. Bauhaus-Archiv, Berlin 2008.

[20] Winfried Nerdinger, *Walter Gropius: Der Architekt Walter Gropius*. Zeichnungen Pläne Fotos Werkverzeichnis, Verlag, Mann, Berlin 1985.

[21] *Kornsilo aus Eisenbeton in Minneapolis*, Minn., in «Zement und Beton», 1908, pp. 329–330.

[22] *Der neue Riesenstockwerkelevator aus Eisenbeton, errichtet von der Baltimore-und Ohio-Eisenbahngesellschaft in Baltimore*, in «Beton und Eisen», 8(10), July 22, 1909, pp. 244–245.

[23] *Amerikanischer Speicherbau*, in «Eisenbeton» 21, November 8, 1909, pp. 205–208.

[24] *Druckversuche in Buenos Aires*, in «Beton und Eisen» 9(3), February 20, 1910, pp. 76–77.

[25] *Wayss und Freytag*, brochure from in «Beton und Eisen», 5, 1910, pp. 15, 19

[26] For further information: https://www.wf-ib.de/en/about-us/history/from-1900/ (last consultation: 14 september 2023).

[27] Denise Ulivieri, *Architettura industriale d'autore. L'ingegnere genovese Cristoforo Bozano e i Silos Granari di Livorno*, in *Il «Silos granario» nel porto di Livorno. Da Architettura dell'Economia a Landmark Urbano*, a cura di Andrea Cecconi, Olimpia Vaccari, Pacini Editore, Pisa 2019, pp.99-127.

[28] Stefania Landi, *Grain Silos from the Thirties in Italy. Analysis, conservation and adaptive reuse*, Pisa University Press, Sesto Fiorentino 2021.

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