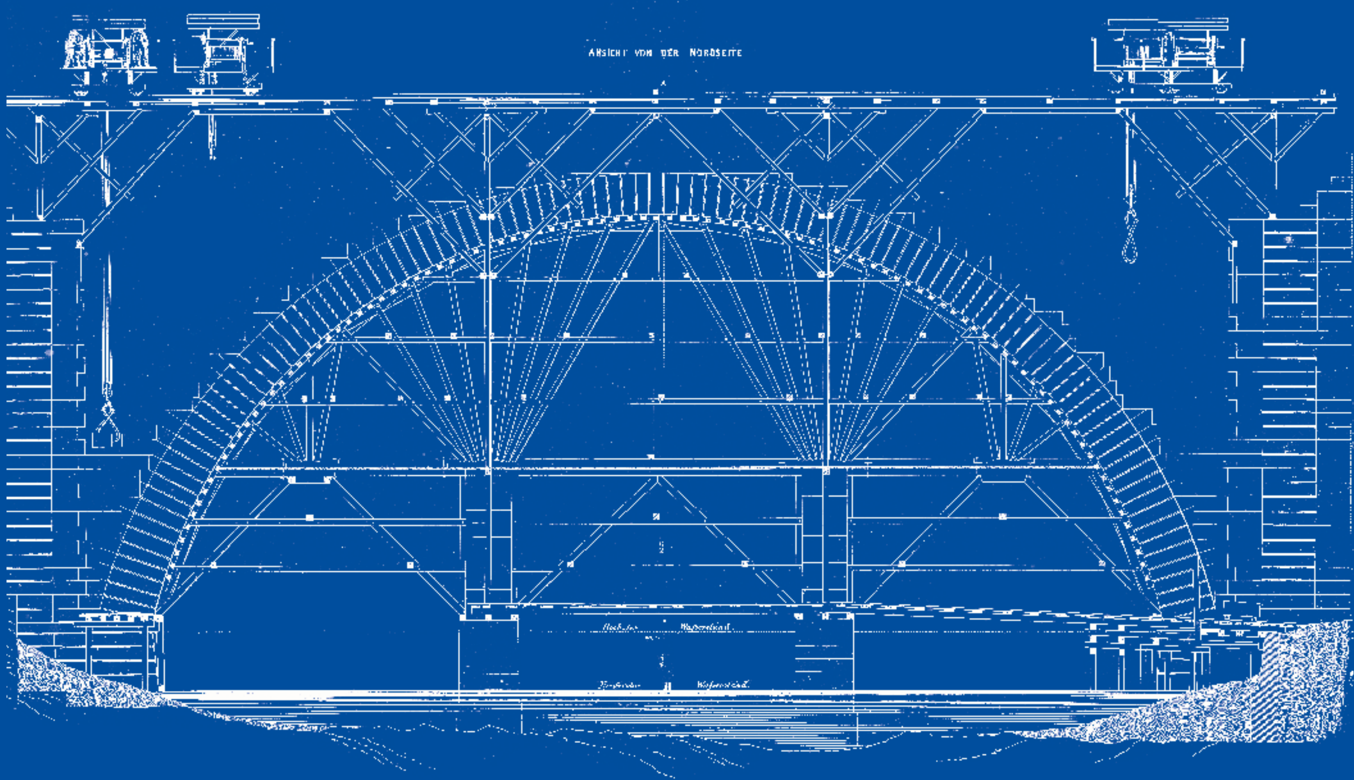
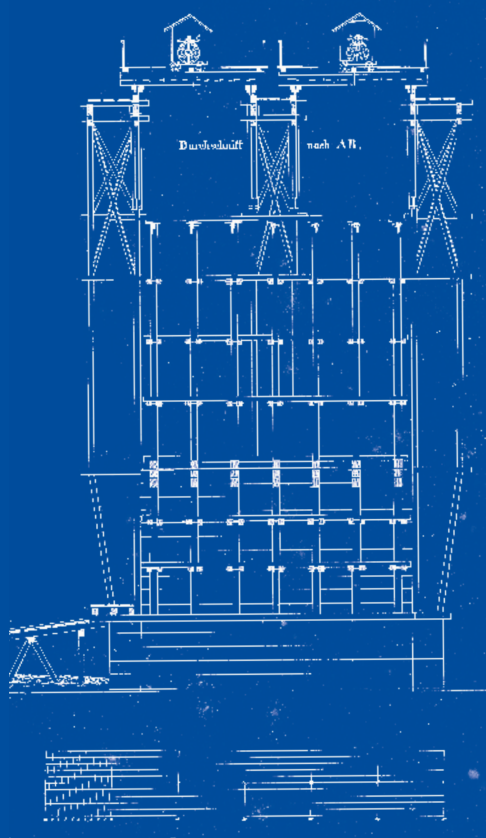
Proceedings of the 8th International Congress on Construction History

Stefan Holzer, Silke Langenberg, Clemens Knobling, Orkun Kasap (Eds.)



Construction Matters



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Scientific Committee

The scientific committee of the 8ICCH consists of distinguished international experts in specific fields and topics within the discipline of construction history. It is responsible for the selection and review of submitted abstracts and papers.

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The Eighth International Congress on Construction History

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Abstract: While the triennial international conferences on Construction History have already reached their eighth instance, Construction History is still a fairly new and small but quickly evolving field. The current trends in Construction History are well reflected in the papers of the present conference. Construction History has strong roots in the historiography of the 19th century and the evolution of industrialization, but the focus of our research field has meanwhile shifted notably to include more recent and also more distant histories as well. This is reflected in these conference proceedings, where 65 out of 148 contributed papers deal with the built heritage or building actors of the 20th or 21st century. The conference also mirrors the wide spectrum of documentary and analytical approaches comprised within the discipline of Construction History. Papers dealing with the technical and functional analysis of specific buildings or building types are complemented by other studies focusing on the lives and formation of building actors, from laborers to architects and engineers, from economical aspects to social and political implications, on legal aspects and the strong ties between the history of construction and the history of engineering sciences.

The conference integrates perfectly into the daily work at the Institute for Preservation and Construction History at ETH Zurich. Its two chairs—the Chair for Building Archaeology and Construction History and the Chair for Construction Heritage and Preservation—endeavor to cover the entire field and to bridge the gaps between the different approaches, methodologies and disciplines, between various centuries as well as technologies—learning together and from each other. We are confident that the proceedings of 8ICCH give a representative picture of the state of the art in our field, and will serve as a reference point for future studies, not just for our own institute, but also for the entire Construction History community.

A bit of statistics

The 8th International Congress on Construction History took place at ETH Zurich, the Swiss Federal Institute of Technology, from June 24 to June 28, 2024. It was hosted by the Institute for Preservation and Construction History (IDB), which is part of the Department of Architecture (D-ARCH).

The congress has brought together around 220 participants from four continents. 185 participants came from European countries, whilst 16 Americans, 12 Asians and 4 persons from Australian/Oceania attended. Unfortunately, there were no African participants, although an entire session of the conference was dedicated to topics of African construction history, and a few abstracts had been submitted by researchers working on that continent. The largest group of European attendees unsurprisingly came from Switzerland (47), followed by strong participation from Germany (38), Italy (28) and Belgium (23). This reflects to some extent the degree to which construction history is established in academia in these countries, although Spain and France, countries that also have a strong academic stance in construction history, were only represented by around ten participants each.

The conference consisted of 148 contributed papers, and four invited plenary keynote lectures. The contributed papers were selected from 328 abstracts originally submitted, resulting in an overall acceptance rate of 45%. All abstracts were reviewed in a double blind review process, by at least two independent reviewers. The authors of the abstracts that had passed this first review process were subsequently asked to supply the full paper. The full papers again underwent a doubly blind review process. Again, each paper was reviewed by at least two independent reviewers. In cases of doubt, the final decision on acceptance or rejection was based on a third review. The scientific committee was formed by 78 recognized experts.

The call for contributions was open to all topics from construction history in its widest sense. However, following an already established tradition of the ICCH conferences, a few specialized topics were suggested by recognized researchers in the field, who offered to solicit papers for dedicated 'thematic sessions'. The suggestions for thematic sessions were also reviewed. After the final review of the full-length papers, 11 special thematic sessions remained. These thematic sessions contained between three and nine contributions each.

Established and new fields of research

The present proceedings reflect the conference organization and schedule faithfully. Each day of the conference (the excursion day on Wednesday excepted), the stage was given to one lecturer who had been invited to deliver a plenary keynote. In selecting the keynote lectures, care was taken to reflect the entire temporal scope of construction history, from antiquity to recent construction. The keynotes included 'Learning from lies in the history of construction (and how to defend against them)', delivered by professor Tullia Iori from the Università degli Studi di Roma Tor Vergata; one of the case studies mentioned in this lecture was the famed bridge over the Adda at Trezzo; therefore, Tullia Iori's exemplary study on this bridge was incorporated into the present proceedings as a substitute for the entire lecture, which covered many other examples as well. The second keynote lecture was given by professor Ine Wouters from Vrije Universiteit Brussel and entitled 'The architectural and structural works of S.A. John Cockerill (1842–1955): balancing between craftmanship and mass production'. Ine Wouters delivered a full-length paper on the keynote lecture, which is also contained in the first section of the present proceedings. By contrast, the other two keynote lecturers abstained from publishing their lectures, and are therefore absent from the present proceedings. Professor Maxime l'Héritier from Université Paris 8 reported on recent findings collected during the post-fire reconstruction of the cathedral of Paris in his lecture entitled 'Notre-Dame de Paris and beyond. Challenges and technical evolutions in gothic construction in the 12th and 13th century'. Finally, professor Alexander von Kienlin from the Technical Universitty of Munich lectured on 'Wide spanning trusses in Greek and Roman Antiquity', thus extending the scope of the conference to antiquity, a topic that was sadly almost entirely absent from the contributed papers. All the keynote lectures gave fascinating insight into current research, and provided a wide overview over the different approaches, topics and methods of construction history.

The final program of the conference consisted of 41 sessions comprising, typically, three or four presentations each. It turned out that not only the contributions to the 'thematic sessions', but also to the open sessions could be grouped quite naturally into tracks and sessions with a clear thematic focus.

In order to avoid simultaneous presentations on thematically closely related topics, the conference was organized in four parallel tracks based on the historic period considered in the respective papers. The thematic sessions could also be incorporated into these four tracks in a very natural way.

The first track, comprising 41 presentations, was dedicated to construction history of the 20th and 21st centuries. A strong focus in this track was on post-war history. The track contained a mini-symposium specifically on 'Construction history of the second half of the 20th and the early 21st century', organized by the ETH Chair for construction Heritage and Preservation. Francisco José Domouso de Alba organized a thematic session on the importance of patents on the development of building structures on 20th century construction. Wesam Al Asali and Alejandra Albuerne Rodríguez prepared a thematic session on the topic of vaulting in the 20th century. Other sessions focused, among other topics, on concrete structures, building actors, and mechanisms of knowledge transfer.

The second track united lectures on topics from the 19th century up to World War I. It harbors the largest of all the thematic sessions, comprising no less than nine lectures. Inge Bertels and Mike Chrimes had invited the contributors to consider 'Construction contractors. New perspectives on the culture of construction from the 18th to the 20th century'. While none of the contributions of this mini-symposium focused on the 18th century, the time frame indicated by the second track was completely covered. The second day of track two also started with a thematic session. It was organized by Laurens Bulckaen and Rika Devos and focused on 'Collaboration in historical buildings: self-evident but intangible'. One last thematic session in the 19th century track, covering 'Transnational bridges: Construction history through the eyes of migrants', was organized by Eberhard Pelke, Karl-Eugen Kurrer and Jana Keck. With these mini-symposia, the 19th century conference track received a very strong emphasis on the building actors, besides the constructions themselves. However, there were still ample contributions to fill, among others, sessions on 19th century bridges, timber structures, construction site process, and further topics.

A considerable number of contributions to the conference also dealt with topics reaching back to the medieval and early modern period. These were united to form the third parallel track. Although not specifically asked for, a sufficient number of contributions focusing on arches and vaults, covering both bridges and buildings, was submitted to fill an entire day of the conference with this topic. This documents a lasting interest in the analysis of vaulting, perhaps the main driving force at all for construction historians to consider pre-1800 structures. While this sequence of sessions could have passed as a mini-symposium of its own, no specific thematic sessions were submitted for this track, except for Kai Kappel's and Klaus Tragbar's short thematic session on 'Building services and living comfort in medieval residences and places of leisure in the Mediterranean region'. Most of the other contributions in the track on medieval and early modern topics could be grouped according the principal building materials employed, ranging from timber through brick and stone to early uses of metals.

Apart from the contributions that could be clearly associated with a certain historic period, several researchers also submitted papers that tried to establish diachronic links, or addressed more general topics such as methodological approaches. Notably, this track included a thematic session organized by Michela Barbot, Robert Carvais, Emmanuel Château-Dutier and Valérie Nègre, posing the question 'How might Prosopography help Construction History?' This call attracted no less than seven answers. Chang-Xue Shu managed to collect four contributions for a thematic session on 'How construction history shaped globalisation: The 19th and 20th century Eurasian cases'. Another very comprehensive thematic session was organized by Stephanie van de Voorde, Ine Wouters, Philippe Bernardi and Maxime L'Héritier. It widened the scope of construction history to include the new, hitherto unconsidered topic of 'Deconstruction, salvage and reuse in a larger perspective'. The fact that this mini-symposium resulted in no less than six accepted papers documents the lively interest in this topic, which as far-reaching implications in today's debates about sustainability and resource-efficient construction. Linda Clarke and Christine Wall, both of whom were unfortunately unable to attend the conference in person, managed to compose a very interesting thematic session on 'Construction labor in times of crisis', which attracted four contributions highlighting diverse interpretations of the term 'crisis'. Besides these mini-symposia, the fourth track also harbored one session on specifically African, as well as one on Asian topics, as well as a further session on construction site processes and the mechanisms of knowledge transfer.

The general sessions, and particularly the thematic sessions, document an increasing interest of construction history that reaches beyond the built object itself, to emphasize the actors driving the whole process of building, from the conception of the initial design, its financing and social and legislative circumstances, to the execution and the engagement of the workers on site. While regard to the humans is implicitly present in all historiography, including construction history and other branches of history of technology, specifically highlighting the actors' roles is a fairly new trend in construction history. New perspectives are also opened by considering issues of sustainability, resilience, and reuse, which naturally reach beyond the process of constructing a building, to include issues of use, maintenance, repair, destruction, and salvage of materials.

Organization of the present volume of proceedings

The present volume of proceedings mirrors the organization of the conference itself. It starts with the two contributions of plenary speakers Tullia Iori and Ine Wouters. The rest of the volume follows the four parallel tracks of the congress. It starts with the papers on 20th and 21st century construction history, incorporating the mini-symposia, followed by the papers contributed to the open sessions, grouped by topics as during the conference itself. Where the organizers of thematic sessions have prepared introductions to their sessions, these introductions precede the papers.

The second part of the proceedings contains the papers on 19th and early 20th century topics, again starting with the mini-symposia, and followed by the contributions to the open sessions, sorted by topics.

The third part unites the studies on medieval and early modern topics, starting with the introduction and the three papers of the short thematic session on medieval building services and living comfort. This is followed by the contributed papers, notably the long series of studies considering vaulted bridges, arches and vaults in medieval and early modern buildings.

The volume concludes with the diachronic and more methodologically oriented studies which formed the fourth and last parallel tracks of the conference. Again, thus section starts with the specific thematic sessions, followed by the papers on various topics.

Excursions and first-hand experiences

Like the preceding ICCH conferences, the 8ICCH also included a full day of excursions. This gave the participants the possibility to visit important sites and objects of construction history in and around Zurich. The excursions covered a wide range of topics and periods. A visit to the former Cistercian abbey of Kappel am Albis provided the participants a unique opportunity to gain insight into medieval construction. The tour considered both the stonework and vaults, and included an ascent to the attics with their original roof structure from 1304. Two excursions targeted historic timber structures. Switzerland is a country with abundant timber supply, laying the grounds for a comprehensive built heritage of timber structures. These were considered in an excursion to the bridges on the Sitter near St. Gall, as well as a visit to several early modern and 19th century roof trusses of buildings in Zurich. Iron as a construction material was discussed during an excursion to several railway bridges in the Zurich region and neighboring Germany, ranging from the 1859 lattice girder bridge across the Rhine near Waldshut to the late 19th century bridges of the Wutach railway. The 19th century was also addressed in a visit to the only room of the ETH main building that still conserves its original shape as designed by Gottfried Semper, the Aula, which has recently undergone comprehensive restoration works. Restoration works were also a topic of a visit to Zurich's late 19th and early 20th century's Tonhalle and Congress Building close to the lake.

Another excursion led to one of Switzerland's UNESCO World Heritage sites, the Albula railway line, dating back to the first decade of the 20th century, and famous for its masonry viaducts, bridges and helical tunnel.

Two excursions considered post-war and contemporary built heritage, the Post Distribution Centre in Zurich-Müllingen and the EMPA NEST building, as well as ETH's robotic labs.

The excursion, led by experts in their fields, provided unique experiences such as walking on top of medieval vaults, visiting roof spaces normally closed to the public, and crossing rivers on foot via railway bridges. Some excursions also included hikes in Switzerland's beautiful landscape. All excursions led to inspired discussions on site, and a lively exchange between participants that was not always restricted to construction history topics, but also established new international contacts and exchange.

Acknowledgements

A great conference like 8ICCH requires contributions from many people to result in a success. Naturally, all authors and presenters deserve a warm thank-you for their engagement. More thanks go to the organizers of the thematic sessions, which offer a great opportunity to get a glimpse of nascent research topics and new trends within the discipline.

However, the conference would have been impossible without the engagement of a few persons who took the immense burden of organization on their shoulders. In the first place, we have to express our gratitude to Dr. Clemens Knobling, who set up the scientific infrastructure of the conference, organized the web site, the calls for contributions, collected the abstracts and reviews, handled communication with the scientific board, and made the conference come to life. Clemens Knobling, who left our institute in January. 2024, transferred all his tasks to Tobias Listl, who took over seamlessly. The entire process of the conference organization was accompanied from start to end by Orkun Kasap. We thank our former and active collaborators very much for their engagement, reliability, ceaseless effort, and passion.

Besides, a large part of the scientific work behind the scenes is always carried by the scientific committee. The members had to read all 328 abstracts, and considerably more than the 148 full papers that finally made it to the proceedings. Some members of the scientific committee reviewed more than twenty papers. We know that the work of reviewing papers for a conference can easily take an entire week of labor, and is sometimes a very tiresome occupation, which nevertheless requires a lot of diligence, attention, and fairness. Although reviewing papers for a conference is one of the honorable tasks that come along with the scientific profession, it is therefore always difficult to find enough reviewers that provide a substantial, in-depth and helpful feedback. Thanks a lot for your great engagement!

Finally, we would like to thank the organizers of the excursions, notably those that came from outside our institute, namely professor Philip Caston, Neubrandenburg, and Dr. Clemens Voigts, Munich.

8th International Congress on Construction History – Zurich

Precast thin shells for industrial buildings. The international journey of the Silberkuhl system (1950–1970)

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Abstract: Among the numerous construction solutions elaborated during the twentieth century, the development of shape-resistant elements represents a pivotal aspect in describing the evolution of industrial buildings. In particular, thanks to the formulation of the membrane theory, reinforced concrete thin shells were largely applied from the 1920s to the 1970s, reducing the time, cost, and materials needed for the construction process. In this framework, the so-called Silberkuhl system for precast shell roofing elements stood out for its numerous international applications to industrial buildings, in Europe and abroad, up to the late 1970s. The spreading of the system invented by the German engineer Wilhelm Johannes Silberkuhl (1912–1984) in the 1950s, was supported by a wide set of industrial patents filed throughout European countries, the US, and Japan, and the action of local dealers. In Italy, the system was first registered in 1958 and widely applied to industrial buildings in the 1960s, up to the late 1970s, by the joined action of national designers and construction firms. The present paper describes the evolution of the system following its local transfers, according to the industrial patents paths, and focuses on the national application of the Silberkuhl system in Italy, describing as a case study the Magazzini Merci Rinascente in Rome (1962).

Introduction

During the twentieth century, industrial buildings represented an "ideal laboratory" for experimentation and innovation in the building process. The architectural characteristics of the industrial buildings—such as large spans and modularity of the inner spaces—encouraged the development of standardized structural elements, especially for roofing systems. In particular, the "shape resistant" elements in reinforced concrete—such as shells and thin vaults exploiting the membrane theory (Joedicke 1963)—were widely applied from the 1920s to the 1970s, according to their convenience in terms of structural efficiency and economy of construction. In the second half of the century, the massive industrialization of the building process transformed the traditional conception of the structural elements, enriching the standardization issues, typical of the industrial buildings, with the constraints of the prefabrication process (Koncz 1969).

In this productive and technological framework, the precast shells designed by the German engineer Wilhelm Johannes Silberkuhl (1912–1984) (Stiglat 2004, 394) stood out for the construction of industrial buildings, from the 1950s until the late 1970s, counting on a broad international diffusion comparable to the Zeiss & Dywidag system (May 2015) in the first half of the century. The Silberkuhl shells, widely published in manuals and technical literature of the time (Joedike 1963; Koncz 1971; Otto 1974; Ramashawy 1974), were considered an outstanding example of precast roofing systems for large spans, exploiting a structural-effective geometry combined with prestressing technique. Furthermore, the construction process of the shells envisaged the possibility of both industrial production and on-site precast, adapting to different economic and technological backgrounds (Cocco 2023).

1. Silberkuhl business and inventions

In the 1930s Silberkuhl studied architecture and engineering at the Hannover Technical University with the aim of industrial planning and industrial building. After graduation, in 1935, Silberkuhl leads, with his professor Otto Fiederling (1892–1972) an industrial planning office. In 1947, he was assistant and lecturer at the Technical University of Hannover (Stiglat 2004, 394). Between 1948 and 1953 he moved to south America—his stay in Argentina is documented in (Cwik 2009, 85–103; Lütge 1980)—with the aim to enlarge his business on industrial buildings design and construction. In Argentina, Silberkuhl tested a roofing system for industrial buildings composed of hyperploid-shaped shells in reinforced concrete for the Aspersion factory in Buenos Aires (Lütge 1980, 374). In 1954 he returned to West Germany and founded his Architektur und Ingenieurbüro Silberkuhl in Essen. In 1959 the bureau was transformed in the company Normko-Gesellschaft (company for standardized construction and statics), which, in 1962, was renamed Ageplan (company for industrial planning), with him as the main shareholder. The main business of the Silberkuhl company was the application of patents developed according to his ideas—tested in Argentina—for structural elements of industrial buildings. Between 1956 and 1979, under the name Silberkuhl a wide set of industrial patents was filed, throughout European countries, the US, and Japan, supporting the spreading of the system for large-span roofing for industrial buildings, throughout the action of Silberkuhl's own company, who was responsible for the structural calculations, and local dealers.

The Silberkuhl systems for industrial large-span roofing comprise five typologies (Fig. 1):

- KS-shell roofing with steel lattice girder and precast concrete slabs (1954);
- HP-shell roofing units in precast prestressed concrete (1956–1967);
- corrugated cross-section roofing elements in lightweight fiber-reinforced materials (1971);
- U-shaped arched thin roofing elements in lightweight fiber-reinforced materials (1971);
- symmetrical curved thin shell roofing elements in reinforced concrete (1979).

Each typology proposes a modular precast roofing solution based on the idea of form-resistant structures, able to cover large spans for production needs and guarantee uniform natural lighting and ventilation. Silberkuhl has explored the use of different materials, from reinforced concrete to fiber-reinforced materials, to obtain lightweight construction solutions and optimize the transport and assembly; furthermore, he developed original equipment able to speed up the in-situ construction process of his modular elements.

1.1. KS-shell roofing with steel lattice girder and precast concrete slabs (1954)

The patent for the conically curved (KS) shell roofing system was filed by Silberkuhl in Germany in 1954 (DE Patent n. 1011604), followed by the Swiss (SW Patent n. 338950), the English (GB Patent n. 785854), Spanish (ES Patent n. 225699), and Austrian (AT Patent n. 212540) ones in the following year.

The system consists of a cylindrical saw-tooth roofing that can reach 60 m spans, composed of circular steel lattice girders for the supports and reinforced concrete precast slabs for the cylindrical shell, spanning between them. The lattice girders are used as scaffolding during the construction and come with welded steel connections along the longitudinal edges. The shell slabs (around 11 cm thick and 7.20 m long), suitable for mass production, are assembled in sequence. The long edges are toothed to increase the coupling, while the short ones present steel wires. To ensure the bond between shell slabs and lattice girder, steel connections are screwed and concrete is poured into the joints. After the slabs have been installed, the tie-rods of the steel lattice girders are tensioned (Joedicke 1963, 93–95). (Fig. 2)

In such a system, the shell can be considered in a membrane state of stress; therefore, increasing the span length causes only a slight increase in the material required for the construction, making the system convenient for large-span roofing structures (Koncz 1971, 260–261).

1.2. HP-shell roofing units in precast prestressed concrete (1956–1967)

The first industrial patents for hyperbolic paraboloids (HP) shells system were filed by Silberkuhl in Germany in 1956 (DE Patent n. 1031948; DE Patent n. 1052660) and 1957 (DE Patent n. 1053762).

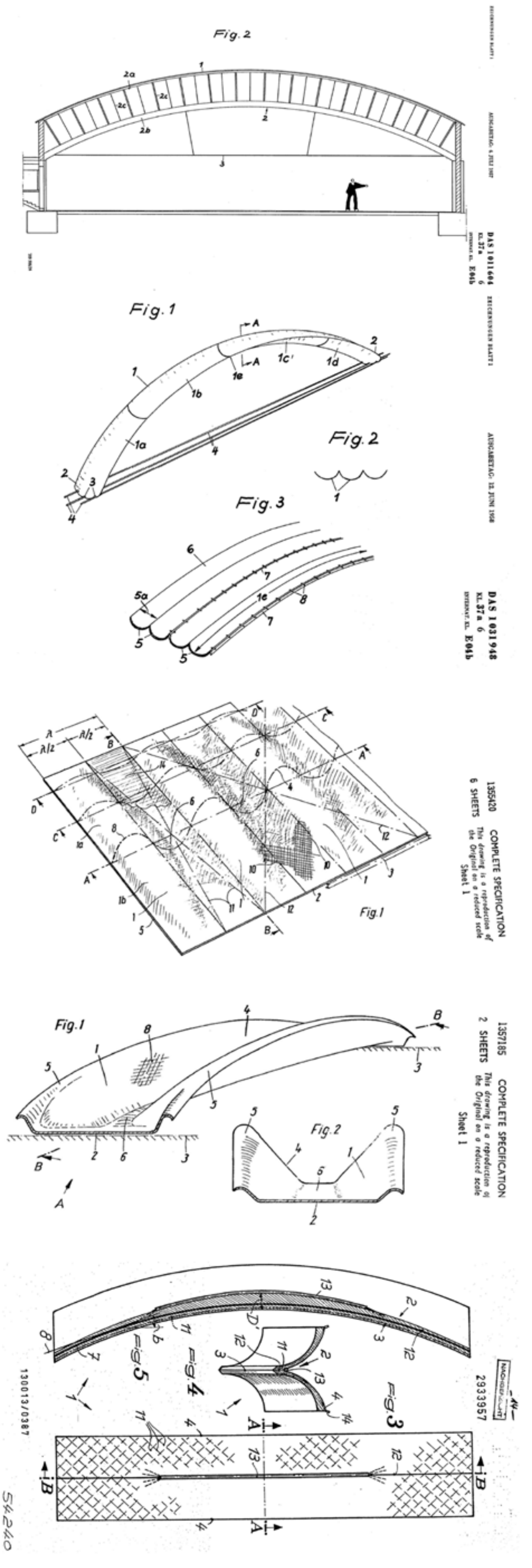

Figure 1. Drawings of Silberkuhl's patents for large-span roofing. From the top: the KS-shell roofing system (DE n. 1011604), the HP-shell roofing element (DE n. 1031948), the corrugated cross-section roofing element (GB n. 355420), the U-shaped arched thin roofing element (GB n. 1357185), and the symmetrical curved thin shell roofing element (DE n. 2933957).

The patents were apparently based on the system applied by Silberkuhl in Argentina, in 1950, for the Asperion factory in Buenos Aires (Lütge 1980, 374) and presented a modular roofing system composed of a sequence of doubly curved thin precast units (about 5–7 cm thick, 20–25 m long, and 2.50 m wide), having the shape of a sector of a hyperbolic paraboloid or hyperboloid with concave upward, simply supported by lateral tympana (Silberkuhl 1961, 428–430). A shell with such a negative Gaussian curvature can be realized without longitudinal edge beams since the shape itself contrasts the uniform loads effectively, resulting in a simpler construction process and improved aesthetic appearance (DE Patent n. 1271348; GB Patent n. 869717). Moreover, designing the shell with specific relations among its geometrical parameters allows minimizing the transverse bending moments and having better conditions in terms of stability (US Patent n. 3142136). In 1954, the German engineer Herbert Müller developed and patented a very similar HP-shell, later applied in Est German as Schalenmüller system (Schaeffler 2017). (Fig. 3)

This typology of roofing system has been improved by Silberkuhl over two decades, producing several patents and three sub-types of construction solutions for contrast outward thrust at the supports, each one with its own peculiar structural behavior. In 1967, the HP-shells system presented three structural solutions (Joedicke 1963, 206–209) (Fig. 4):

- the first type was lightly reinforced and characterized by a post-tensioned tie-rod that connected the end points, placed externally or internally to the body of the shell (DE Patent n. 1271348); from a structural point of view, this element acts as a thin-walled arch;
- the second type did not have a tie-rod but incorporated a central stiffening rib; in this case, the element works as a thin-walled beam with a curved centroidal rib;
- the third type avoided the tie-rod and the central rib, employing prestressing along its whole width (DE Patent n. 1053762); in this latter case, the element is a hybrid shell, combining a membrane behavior with light prestressing.

Figure 2. Application of the KS-shell to the Watney Mann Brewery, Isleworth, Hounslow, Greater London Authority (Historic England Archive, John Laing Photographic Collection, 1968).

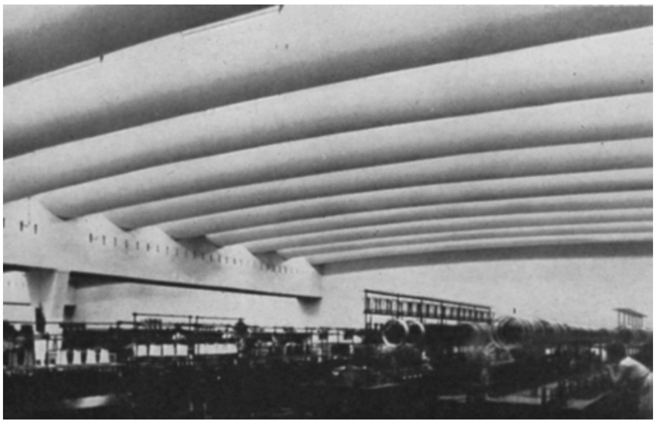

Figure 3. Application in England of the HP-shell (*A new hyperbolic shell roof*, 1958).

Taking advantage of the ruled-surface nature of the HP, the reinforcement is composed of two intersecting sets of straight prestressing wires, laid on the crossing generatrixes of the HP, and a light welded steel net. The position of the prestressing wires varies along the elements, according to the state of stress: lower position at the center, where the bending moments are largest and the shear forces are least; higher position at the edges, where the bending moments decrease and the shear forces increase (Koncz 1971, 248–249).

In 1959 Silberkuhl also conceived a solution to use the HP element as a duct for heating or cooling fluids, covering the shells with a series of flat precast plates adjacent to one another. In order to provide an efficient and strong connection, the cover plates are provided with corrugation along the edges and should be placed while the concrete of the shell is not completely hardened (US Patent n. 3184892).

A second solution for realizing duct for air circulation was patented in 1960 in German (DE Patent n. 69587), then in 1961 in the United States (US Patent n. 3207054) and Italy (IT Patent n. 652266). Corrugated sheets can be used to obtain a lighter and more economical covering for the HP elements, placing them in the axial direction of the barrel vault. In this way, the structure does not require any further external reinforcements, achieving higher resistance with lower construction complexity. In these patents, Silberkuhl also solved the problem of torsional stresses that may arise in the HP element from thermal expansion, proposing the introduction of thin connecting plates in fiber-cement sheets (i.e., asbestos cement) located between the HP elements.

In order to improve the load bearing and the shear-resisting capacity of the elements, avoiding an increase in the overall weight, in 1963 Silberkuhl also proposed a shell section with a gradual change in its thickness from the central cross-section to the edges (US Patent n. 3296754). In France, in 1965, he also patented a complete saw-tooth roofing system, arranging the HP-shell elements sloped and alternating them with glazed sections (FR Patent n. 1391628).

Special machinery was designed and patented to prefabricate the HP-shells—on-site or off-site—by smoothing the upper surface of the element, poured in a mold, with the aid of an arch-shaped vibratory slider (US Patent n. 3132404). For the assembly phase of the shell, the lightness of the elements and the presence of stiffening in the two directions allow the use of a single crane, speeding up further the construction process.

1.3. Corrugated cross-section roofing elements in lightweight fiber-reinforced materials (1971)

The patent for corrugated cross-section roofing was filed in Great Britain in 1971 (GB Patent n. 1355420). Silberkuhl proposed a modular wave-shaped roof with a constant “wavelength” and variable “amplitude”, decreasing to zero at the edge. The length of each module should be between 3 and 10 times the wavelength. The module can have two main forms: a single-curved section with straight longitudinal edges or a doubly-curved section with arched longitudinal edges but straight in plan.

Such elements can be prefabricated in reinforced concrete, fiber-reinforced material, and plastics. The solution elaborated by Silberkuhl reduces the weight of prefabricated units and simplifies the transportation and assembly phases.

Figure 4. The three typologies of the Silberkuhl System for HP-shells roofing units (Silberkuhl, 1961a; Joedicke 1963).

1.4. U-shaped arched thin roofing elements in lightweight fiber-reinforced materials (1971)

The U-shaped arched element was patented in 1971 in Great Britain (GB Patent n. 1357185). Silberkuhl conceived this prefabricated module as both roof or wall panels, applying fiber-reinforced concrete to keep the construction elements thin and lightweight, even if the width increases. Each element is rectangular in plan and transversally corrugated; it has flat support edges at the short side, U-shape in the transverse section, and arched hyperbolic curvature along the longitudinal direction. This double curvature guarantees the member’s high strength, stiffness, and stability.

The connection between two consecutive modules is ensured by the peculiar hollow profile of the long side, which also stiffens and stabilizes the overall roof structure. Moreover, the element can be coupled with conventional corrugated sheets of fiber-reinforced concrete, such as asbestos cement sheets, or reinforced with thin longitudinal ribs at the bottom of the central section if the load-carrying requirements increase.

1.5. Symmetrical curved thin shell roofing elements in reinforced concrete (1979)

The patent for the symmetrical curved thin shell roofing elements was filed in Germany in 1979 (DE Patent n. 2927779; DE patent n. 2933957), followed in the same year by that for the production machinery (DE Patent n. 2933923).

According to this invention, the shell roofing element is composed of two symmetrical hyperbolic or toroidal sections, forming a V-shape. The convex upward curvature of the element along the longitudinal direction guarantees the stiffness of the structure. The transverse shell section of the element has increasing thickness from the lower to the upper edges. The thickness increases according to the cosine of the angle of the straight-line tangent to the curvature. This expedient improves the strength of the element, allowing off-site prefabrication and safe transportation. The reinforcements should preferably be arranged at 45° and placed in a single layer: in the upper area along the longitudinal edges and the lower area at the centerline.

In the German patent n. 2927779, Silberkuhl proposed the same curved section also for the support elements, optimizing their weight and reducing the stress in the nodes. The production machinery is composed of a sliding formwork, able to shape, distribute, and compact the concrete during the pouring phase, hence speeding up the construction process.

2. The journey of the Silberkuhl system

Between 1956 and 1980, the Silberkuhl patents for industrial shell-roofing, especially the KS-shells and the HP-shells, were filed in different countries. According to the patents priority, the systems were first applied in Germany, Swiss, United Kingdom, France, and Belgium, then in Italy, the United States, and Latin America, probably exploiting the network created in the 1950s.

The German diffusion of the systems was directed by the Silberkuhl’s firm. The workshop of the Porsche Industry in Friedrichshafen (1955–56), the Keller + Knappich in

Augsburg (1958–59), the Ford in Köln (1960–61) were documented as first uses of the KS-shells (Silberkuhl, 1961a).

The international dissemination of the system was ruled by the license of the industrial patents, filed in German at first by the Silberkuhl head office in Essen, and then granted to local dealers. The first international dealer of the system, and the most affirmed until the late 1970s, was the association of two England-based companies, the ATA-Industrial Company and the Modern Engineering Limited.

In 1957, the companies acquired the license of the 1954-patent for KS-shells and the 1956 patent for HP-shells with the aim to apply the two systems to industrial buildings, exploiting both the steel and the reinforced concrete path, on the building market of England and the Commonwealth (for the latter, the application of the first system was promoted by the British Steel and Iron Federation).

The KS-shells system was first applied in 1957 for the building of the Thames Board Mills Limited company in Purfleet (A new large-span construction System, 1957). The building, featuring a roof surface of 6,000 square meters with 36 m-spans, was an outstanding example for the effectiveness of the system in terms of time and costs. If the basic economy derived from the use of steel and reinforced concrete in their optimum state (the steel being in tension and the concrete in compression), the economy and the rapidity of construction were enforced by the construction process that avoids the use of scaffolding: indeed, the steel arches, prefabricated afar from the site, supported the shuttering of the concrete shells by themselves. The system exhibited even strong functionality in terms of lighting of the inner spaces, with a strong impact on the architecture of the factory: the construction of the roof was essentially a north-light design and the shape of the concrete shells ensured the natural light distribution. Significant late applications of the KS-shell were the bottling store of the brewery Watneys in London, built by John Lang Ltd in 1968, and the warehouse of the W. H. Smith & Sons Ltd in London (Marsden 2012).

The HP system was first applied in 1958 when the company Modern Engineering Limited launched the production of the HP shells in its plant in Bristol, with the aim at organizing the manufacturing of the shell on a national basis (*A New Hyperbolic Shell Roof*, 1958). The shells, tested with tie-rod and rib at first, were produced in the standard dimensions: 19.8 m span, 5 cm thickness, and 1.8 m width, according to the fully prestressed type, as described in the patent. The HP-shells were first applied together with the KS to the building of the Modern Engineering Limited own workshop. To produce and employ the HP-shells, the Modern Engineering opened a new section, named Modern Concrete: between the 1960s and the late 1970s the application of the shell by Modern Concrete was documented for a wide set of building typologies. Among them, the Daily Market in Blackburn represented a noteworthy case of HP-shell use (Marsden 2012).

Among the other documented case histories of use of the Silberkuhl system in European countries, one of the most notable is the French application of the HP-shell system for the construction of prefabricated swimming pools, within a program launched by the government in 1965. The Silberkuhl HP-shell system became part of a commercial model of swimming pool which, called PIAM Piscines industrialisées à accroissement multiple (PIAM Vorgefertigte Schwimmhallen aus Frankreich 1968), featured a broad diffusion all over the country (*Gerpiam Advertisment* 1968).

In The Netherlands the system was spread by the company Von Havenwerken N.V based in Amsterdam, while in Portugal, the system was diffused by the Indubel construction company, specialized in reinforced concrete, which produced the vaults in a novel plant based in Albarraque (Indubel Adverstising). The use of the system outside Europe was documented in USA, India, Iraq (Ramashawy 1974), and Japan (Kawaguchi 1997).

3. Silberkuhl system in Italy

In Italy, the Silberkuhl system approached in 1958, following the fast rise of the industrial sector of the country, in the so-called economic miracle age.

A first patent, filed in 1957 (IT Patent n. 594834), consisted of a light roofing system based on the combination of asbestos cement panel, featuring an undulated shape, and a steel lattice composed of tubular elements; the patent directly referred to the German one, and it was registered in the name of Silberkuhl together with Uwe Kastl and Ernst Haeussler, both employees of the German head office. The singularity of the invention stood in the attribution of a static role to the asbestos cement panel that worked, at the same, as a roofing and as tie-rod element in the layout of the triangular structural module.

A second patent was filed in 1961, in the name of Silberkuhl together with Kastl and Haeussler, and concerned the HP-shells system (IT Patent n. 652266). The patent directly referred to the 1960 German patent (DE Patent n. 69587) and described the system of HP vaults in reinforced concrete, with special reference to the assembly configuration of a series of HP vaults and light panels, in asbestos cement, described in the 1957 Italian patent. To ensure the connection between the reinforced concrete HP vault and the plate in asbestos cement, a special edge device was designed, exploiting synthetic material: the combination of the vault and the plate had, firstly, a static role, transforming the thin shell in a tubular structure. Furthermore, the void between the reinforced concrete vault and the roofing plate was conceived to host the air conducts for the climatization of the inner spaces or the addition of thermal insulating material. This building detail guaranteed the integration of thermal insulation or mechanical ventilation, and it was added to the original system, composed only by the load-bearing HP vault, especially in case of the application in countries with different climate conditions. In this technological development framework, the system was equipped with a system of water sprinklers for fire protection. (Fig. 5)

A last patent was filed in 1979, in the solo name of Silberkuhl, and concerned a particularly shaped vault (IT Patent n. 1123726). The patent directly referred to the German invention (DE patent n. 2933957) and presented a different geometry thin shell: the shell was composed by two curved wings, with variable cross section, forming a sort of V-shape. The invention was based on existing structural elements with the same shape, perfecting some geometrical details, to allow the industrial production of the elements. In Italy, an industrial plant, built in 1969, featured the use of large-span curved V-shape vaults, constructed on-site, and could had been a direct reference for this patent (Aitec 1970).

The invention focused on a building solution that avoided using strengthened transversal elements, via the study of the variable thickness of the cross-section, increasing from the base of the V to the end of the two wings. Furthermore, the invention featured the use of rebars and prestressing devices, placed at the base of the V.

The patents were first acquired by the engineer Ugolino della Gagliardesca (1925–2017), who became the national dealer of the Silberkuhl patents—with exclusive rights for Italy between 1957 and 1977—especially for the HP vault. In 1966, he operated through four companies that provided the application of the system in the center and the south of the country. In 1966, the Silberkuhl HP-shell was presented at the SAIE exhibition in Bologna, among the most affirmed precast systems for industrial buildings (SAIE Bologna 1966). In the 1970s the license of the HP vault patent was acquired by several construction firms, specialized in precast elements, and located all over the country: between them, the Brenta Prefabbricati for the north, the Centro Sud Prefabbricati, for the center, the Prefabbricati Bari for the south; in 1980 a further company—Sis Italia – Sistemi Industriali Silberkuhl—was purposely founded for the diffusion of the system. All the Italian companies disappeared in the 1990s (Lavizzari 2006).

In the 1970s, the application of the system was extended to developing countries, through the action of the Italian dealers: the Italian construction sites, low-technology and lacking specialized workers, were considered a valid field trial for the application in less industrialized countries, such as the least developed countries. In this economic and productive framework, della Gagliardesca participated personally to the foundation of a plant in Iran, in the city of Samawa, with the Indian company Arvind Construction Company Ltd. The company, specialized in the production of precast HP vaults, within the plant and on-site, remained in activity until the 1990s.

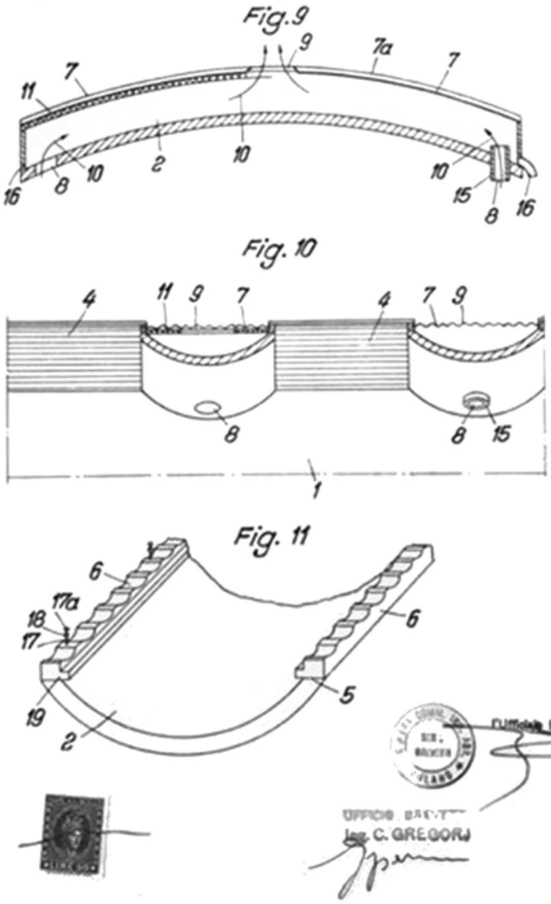

Figure 5. Drawings of the 1961 Italian patent (IT n. 652266).

3.1. The Magazzini Merci Rinascente in Rome

A noteworthy example of the HP-shell system application in Italy was the roof of building Magazzini Merci Rinascente in Rome, designed in 1960 by the engineers Aldo Molteni and Eugenio Jaccod for the contractor Società Edile Lavori Pubblici e Industriali (SELPI) (Magazzino Merci La Rinascente, Rome, Correspondance, 1961). The Magazzini Merci was the Rome-based hub of the industrial group La Rinascente-SMA, for industrial clothes and food products (*La Rinascente* 1968).

The 25,000 square meters building had a rectangular plan—200 m long and 124.60 m large—, with 6 spans of 20 m each. The roof of the building was composed of 400 HP-shell elements—a free span of 19.80 m, a width of 2.50 m, and a thickness of 5 cm—simply supported by perimetral beams.

The first design hypothesis, conceived in 1957, concerned a fully prefabricated steel structure for a 20,000 square meter building. The structure, which cost 1,000,000,000 lire, was considered too expensive, and the studies were discontinued in 1960. In April 1960, a second study was conducted for a 33,000 square meter building entirely in reinforced concrete. In July, the contractor, SELPI, was in July for the construction, amounting to a total of 1,300,000,000 lire. The construction site opened in August. The contract obliged the contractor to complete the works in only five months, for the central area, and in one year for the entire complex (Magazzino Merci La Rinascente, Rome, Atto di Collaudo, 1964).

To fit the construction schedule, the building process was enhanced by the mixed use of cast-on-site production, for the columns and the beams of the load-bearing frame, and on-site prefabrication. In particular, the HP vaults and slabs were prefabricated on-site; the former with a special device and the latter exploiting metal formworks that could be dismantled.

The beams were designed according to the Silberkuhl patent prescription, to allow the assembled configuration of the roof characterized by shells with different heights, for the zenithal lighting system. The beams acting as supports for the shells had two main geometries: a standard U-shape for the edge beams and a U-shape with extended walls to support the elevated shells. The beams of the central spans were supported by coupled columns and presented a coupled U-shape (Magazzino Merci La Rinascente, Rome, Execution Project, 1960).

The design and construction of the shell followed the Silberkuhl patent prescription, with special attention to the on-site construction process. The geometry of the shell was, thus, generated by exploiting a translation surface: a circular arch with a radius of 2.60 m was shifted on a circular arch with a radius of 25 m. To counteract the horizontal thrust, each shell was equipped with a post-tensioned steel tie-rod, connecting the two ends; the reinforcement layout was characterized by a light-welded steel net. The total weight of the steel used as reinforcement, counting the welded net plus the tie-rod, was 500 kg.

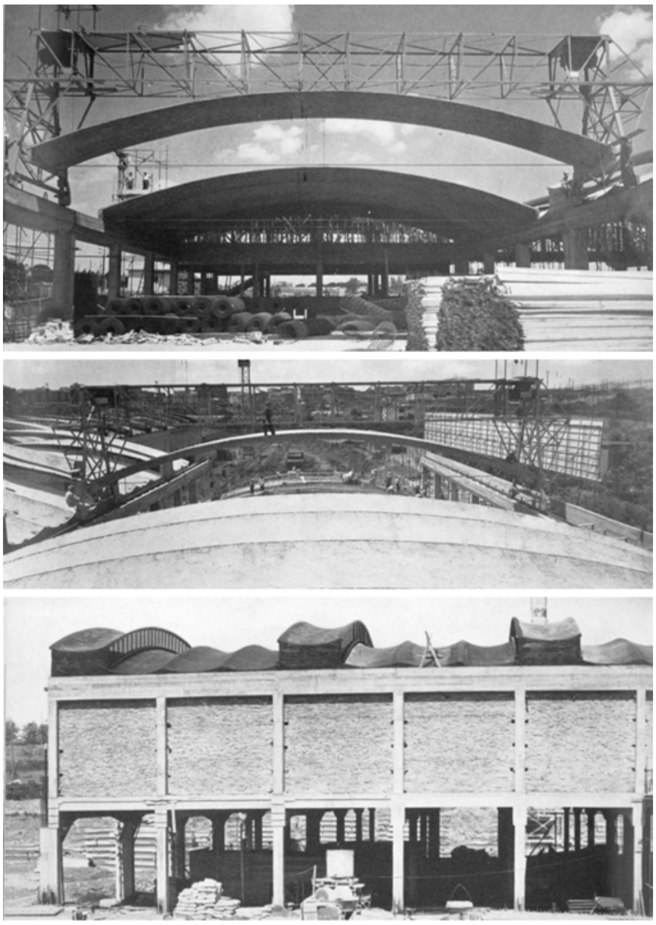

Figure 6. Magazzini Rinascente in Rome: construction site and assembly of the HP-shell, 1961 (Pietroboni 1962).

The on-site execution process of the shells, comprised five main steps: i) a mold composed of wooden board was set up on the ground; ii) a welded steel net was laid on the whole surface of the mold and two steel plates, acting as anchoring devices for the tie-rod, were set at the ends points, together with four steel rings, functioning as a lifting device; iii) concrete was poured and molded by the action of an arch-shaped vibrating slider; iv) after 24-hours curing, the shell was lifted up from the mold, using a single bridge crane (the total weight of the single shell was 9,400 kg), and the tie-rod was tensioned; v) the shell was set up at the roof level exploiting the support of the lateral beam. Steps iv) and v) were carried out in 30 minutes and, thus, the mold was completely reusable for the cast of a further shell; to support the 24-hours curing process together with the workability of the material required in step iii), a special concrete mix design was prepared (Pietroboni 1962). The construction of the main structures ended in 1961; the provisional testing was conducted by the engineer Giovanni Pietroboni, in 1962: in this occasion, the expected structural behavior of the shell was verified with a load test (Magazzino Merci La Rinascente, Rome, Atto di Collaudo, 1964). (Fig. 6)

Conclusion

The application of the Silberkuhl KS- and the HP- shells for the construction of industrial buildings in Europe and abroad from the 1950s until the late 1970s is presented in this paper, through the analysis of technical literature of the time, industrial patents, and archival sources.

The study shows that the knowledge of the Silberkuhl system was spread by the international technical literature of the time—design handbooks and journals—, while the commercial application was led by the industrial patents and the action of local dealers. Furthermore, the study discloses that the HP-shells, conceived for industrial buildings, counted on a broader use for a significant set of different building typologies featuring large spans, ranging from sport halls, markets, schools, and pavilions, underlining the effectiveness of the system in terms of construction cost, structural performances, and aesthetics issues.

The case study of the use of the system in Italy remarks the adaptability of the construction process of the HP shells, which featured the possibility of both industrial production and the on-site precast, according to the different economic and technological backgrounds. In this regard, the case of Italy, where the HP shells were precast on-site, was a significant test for the adaptability of the system to developing countries. Ideally, this path connects in a circular fashion the latest application of the system to the naissance of the Silberkuhl ideas within the traditional construction sites of Argentina in the late 1940s.

Concluding, framed in the international history of prefabrication and industrialized construction, the study remarks the significance of the Silberkuhl systems as a noteworthy example of the global circulation of construction systems and technical knowledge, propelling to further investigation on the local development in different countries.

Acknowledgements

The outcomes presented in this paper are part of a wider research activity, still in progress, on twentieth-century industrial heritage in Italy, with a specific focus on structural conception and construction processes of vaulted roofing systems, within a research collaboration between Sapienza University of Rome and Tor Vergata University of Rome.

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Construction History is still a fairly new and small but quickly evolving field. The current trends in Construction History are well reflected in the papers of the present conference. Construction History has strong roots in the historiography of the 19th century and the evolution of industrialization, but the focus of our research field has meanwhile shifted notably to include more recent and also more distant histories as well. This is reflected in these conference proceedings, where 65 out of 148 contributed papers deal with the built heritage or building actors of the 20th or 21st century. The conference also mirrors the wide spectrum of documentary and analytical approaches comprised within the discipline of Construction History. Papers dealing with the technical and functional analysis of specific buildings or building types are complemented by other studies focusing on the lives and formation of building actors, from laborers to architects and engineers, from economical aspects to social and political implications, on legal aspects and the strong ties between the history of construction and the history of engineering sciences.

The conference integrates perfectly into the daily work at the Institute for Preservation and Construction History at ETH Zurich. Its two chairs – the Chair for Building Archaeology and Construction History and the Chair for Construction Heritage and Preservation – endeavor to cover the entire field and to bridge the gaps between the different approaches, methodologies and disciplines, between various centuries as well as technologies – learning together and from each other. The proceedings of 8ICCH give a representative picture of the state of the art in the field, and will serve as a reference point for future studies.

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