HISTORY OF CONSTRUCTION CULTURES

VOLUME 1

edited by
João Mascarenhas-Mateus
and **Ana Paula Pires**

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HISTORY OF CONSTRUCTION CULTURES

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History of Construction Cultures

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History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)
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Introduction: *History of Construction Cultures*

We are what we build and how we build; thus, the study of Construction History is now more than ever at the centre of current debates as to the shape of a sustainable future for humankind. Embracing that statement, the present work takes the title *History of Construction Cultures* and aims to celebrate and expand our understanding of the ways in which everyday building activities have been perceived and experienced in different cultures, times and places.

This two-volume publication brings together the communications that were presented at the 7ICCH – Seventh International Congress on Construction History, broadcast live from Lisbon, Portugal on 12–16 July 2021. The 7ICCH was organized by the Sociedade Portuguesa de Estudos de História da Construção (Portuguese Society for Construction History Studies – SPEHC); the Lisbon School of Architecture, University of Lisbon; its Research Centre (CIAUD); and the College of Social and Human Sciences of the NOVA University of Lisbon (NOVA FCSH).

This is the first time the International Congresses on Construction History (ICCH) Proceedings will be available in open access format in addition to the traditional printed and digital formats, embracing open science principles and increasing the societal impact of research. The work embodies and reflects the research done in different contexts worldwide in the sphere of Construction History with a view to advancing on the path opened by earlier ICCH editions. The first edition of ICCH took place in Madrid in 2003. Since then, it has been a regular event organized at three-year intervals: Cambridge (2006), Cottbus (2009), Paris (2012), Chicago (2015) and Brussels (2018).

7ICCH focused on the many problems involved in the millennia-old human activity of building practiced in the most diverse cultures of the world, stimulating the cross-over with other disciplines. The response to this broad invitation materialized in 357 paper proposals. A thorough evaluation and selection process involving the International Scientific Committee resulted in the 206 papers of this work, authored by researchers from 37 countries: Australia, Austria, Belgium, Brazil, Bulgaria, Canada, China, Dominican Republic, Ecuador, Egypt, Estonia, France, Germany, India, Iran, Ireland, Italy, Japan, Mexico, Netherlands, New Zealand, Norway, Peru, Poland, Portugal, Puerto Rico, Russia, Serbia, Spain, South Africa, Sweden, Switzerland, Thailand, United Arab Emirates, United Kingdom, United States of America, and Venezuela.

The study of construction cultures entails the analysis of the transformation of a community's knowledge capital expressed in the activity of construction. As such, Construction History is a broad field of knowledge that encompasses all of the actors involved in that activity, whether collective (contractors, materials producers and suppliers, schools, associations, and institutions) or individual (engineers, architects, entrepreneurs, craftsmen). In each given location and historical period, these actors have engaged in building using particular technologies, tools, machines and materials. They have followed specific rules and laws, and transferred knowledge on construction in specific ways. Their activity has had an economic value and belonged to a particular political context, and it has been organized following a set of social and cultural models.

This broad range of issues was debated during the Congress in general open sessions, as well as in special thematic sessions. Open sessions covered a wide variety of aspects related to Construction History. Thematic sessions were selected by the Scientific Committee after a call for proposals: they highlight themes of recent debate, approaches and directions, fostering transnational and interdisciplinary collaboration on promising and propitious subjects. The open sessions topics were:

- Cultural translation of construction cultures: Colonial building processes and autochthonous cultures; hybridization of construction cultures, local interpretation of imported cultures of building; adaptation of building processes to different material conditions;
- The discipline of Construction History: Epistemological issues, methodology; teaching; historiography; sources on Construction History;
- Building actors: Contractors, architects, engineers; master builders, craftspeople, trade unions and guilds; institutions and organizations;
- Building materials: Their history, extraction, transformation and manipulation (timber; earth, brick and tiles; iron and steel; binders; concrete and reinforced concrete; plaster and mortar; glass and glazing; composite materials);

- Building machines, tools and equipment: Simple machines, steam operated-machines, hand tools, pneumatic tools, scaffolding;
- Construction processes: Design, execution and protective operations related to durability and maintenance; organization of the construction site; prefabrication and industrialization; craftsmanship and workshops; foundations, superstructures, roofs, coatings, paint;
- Building services and techniques: Lighting; heating; ventilation; health and comfort;
- Structural theory and analysis: Stereotomy; modelling and simulation; structural theory and structural forms; applied sciences; relation between theory and practice;
- Political, social and economic aspects: Economics of construction; law and juridical aspects; politics and policies; hierarchy of actors; public works and territory management, marketing and propaganda;
- Knowledge transfer: Technical literature, rules and standards; building regulations; training and education; drawings; patents; scientific dissemination, innovations, experiments and events.

The thematic sessions selected were:

- Form with no formwork (vault construction with reduced formwork);
- Understanding the culture of building expertise in situations of uncertainty (Middle Ages-Modern times);
- Historical timber constructions between regional tradition and supra-regional influences;
- Historicizing material properties: Between technological and cultural history;
- South-South cooperation and non-alignment in the construction world 1950s–1980s;
- Construction cultures of the recent past: Building materials and building techniques 1950–2000;
- Hypar concrete shells: A structural, geometric and constructive revolution in the mid-20th century;
- Can engineering culture be improved by construction history?

Volume 1 begins with the open session "Cultural translation of construction cultures" and continues with all of the thematic sessions, each one preceded by an introductory text by the session chairs. The volume ends with the first part of the papers presented at the open sessions, organized chronologically. Volume 2 is dedicated to the remaining topics within the general themes, also in chronological order.

Four keynote speakers were chosen to present their most recent research results on different historical periods: Marco Fabbri on "Building in Ancient Rome: The fortifications of Pompeii"; Stefan Holzer "The role of temporary works on the medieval and early modern construction site"; Vitale Zanchettin "Raphael's architecture: Buildings and materials" and Beatriz Mugayar Kühl "Railways in São Paulo (Brazil): Impacts on the construction culture and on the transformation of the territory".

The editors and the organizers wish to express their immense gratitude to all members of the International Scientific Committee, who, despite the difficult context of the pandemic, worked intensively every time they were called on to give their rigorous evaluation of the different papers.

The 7ICCH was the first congress convened under the aegis of the International Federation of Construction History, founded in July 2018 in Brussels. Therefore, we are also very grateful to all the members of the Federation, composed of the presidents of the British, Spanish, Francophone, German, U.S. and Portuguese Societies and its Belgian co-opted member. A special thanks is due for all the expertise and experience that was passed on by our colleagues who have been organizing this unique and world significant event since 2003, and in particular to our predecessors from all the Belgian universities who organized 6ICCH.

The editors wish to extend their sincerest thanks to authors and co-authors for their support, patience, and efforts. This two-volume work would not exist but for the time, knowledge, and generosity they invested in the initiative.

Our sincere thanks also go out to Kate Major Patience, Terry Lee Little, Kevin Rose and Anne Samson for proofreading every paper included here, and to the team at Taylor & Francis (Netherlands), in particular Germaine Seijger and Leon Bijnsdorp.

Finally, we are grateful to all members of the Local Committee and to the institutions that have supported both the 7ICCH event and the publication of these proceedings.

The Editors
João Mascarenhas-Mateus and Ana Paula Pires

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Open session: Cultural translation of construction cultures

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A reinforced concrete stage tower within a 18th-century masonry theater: The Municipal Theater of Bologna

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ABSTRACT: The Municipal Theater is one of the main artistic symbols of Bologna. Although it is recognized worldwide for its musical history, its construction peculiarities are less known. The original building was designed by the architect Antonio Galli Bibiena in 1763 in a masonry and wood structure. The stage tower, burnt down in 1931, was rebuilt with a reinforced concrete structure, which is currently a significant landmark in the heart of the University district with about 35 m height. The reconstruction project, designed by engineer Armando Villa, faced complex issues for the emerging, but still inexperienced, Italian reinforced concrete technique, such as the installation of a large span roof at considerable heights. Archival research and digital documentation made it possible to analyze the structural concept of this construction, a significant example of the building culture of the 1930s, tracing the evolution of this specific construction system and contextualizing it on the international scene.

1 INTRODUCTION

The Municipal Theater of Bologna (1931–35) stage tower is a meaningful example of the evolution of construction techniques from traditional to modern architecture. On the one hand, the building expresses the research development on reinforced concrete in the Italian and international landscape in the early 20th century. On the other hand, it concerns the relationship between engineering and architecture in modern construction and the contemporary use of new techniques and new design language, with further confirmation, even in the 1930s, of the Italian concept of traditionalist construction.

The introduction of the reinforced concrete frame system in Europe at the end of the 19th century led to the quick substitution of masonry structures. This substitution also gradually happened in Italy, where the new technique was widely and rapidly spreading, with the substantial difference that Italian reinforced concrete structures initially consisted of a mixed structure (Del Piano 1937). The new system did not instantly result in the loss of traditional language linked to wall construction, but the insertion of structural frames in buildings began to change masonry systems, leading to their decisive revision. Even though the mixed construction did not affect the traditional style of buildings, it started to modify their spatial conformation and the new functional needs that it could satisfy (Poretti 2007).

The following phase of great experimentation was made possible by remarkable progress achieved in the scientific and technical field, such as understanding the inapplicability of elastic theory to an anisotropic material, the need for deepening research on plastic behavior, and the understanding of cracking and breaking phenomena. After all, Italian engineering had been univocally directed at improving the knowledge about reinforced concrete structures since the late 19th century, and Schools of Application (*Regie Scuole di Applicazione per gli Ingegneri*) started to teach the new construction technique in the early 20th century. These schools, future technical universities, started to train civil engineers and architects all over Italy. Thanks to Silvio Canevazzi and Attilio Muggia's work, Bologna became a privileged didactic context (Mirri et al. 2019; Mochi & Predari 2012).

Therefore, the new technique's high potentialities started to be tested in construction sites of public works. It was not surprising that very sophisticated structures were hidden within architectures strongly linked to eclectic languages. For instance, it was the case of the covering of Politeama Theater in Prato (1921), and Cinema Augusteo in Naples (1926), both designed by Pierluigi Nervi, and generally in many of the coverings and galleries of cinemas built in those years (Poretti 2008).

This also happened for the construction of the Municipal Theater in Bologna. The compresence of wide volumes and historical characters is evident in the external facades. However, from a functional perspective, the reinforced concrete technique guaranteed benefits that other construction methods could not give, thus conserving traditional forms (Figure 1).

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Figure 1. The stage tower of the Municipal Theater of Bologna in 1935. Andrea Villa's private archive.

Figure 2. The stage tower and the piezometric tower in Bologna's landscape in 1935. Donati & Zanichelli Company's private archive.

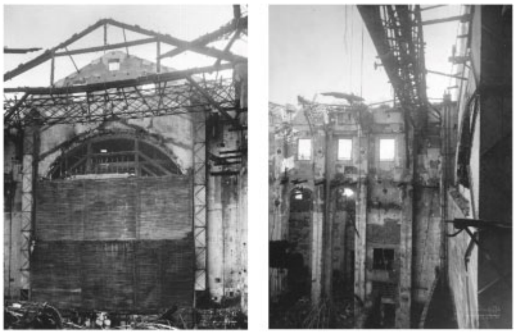

Figure 3, 4. The fire almost destroyed the stage in 1931. Donati & Zanichelli Company's private archive.

2 THE MUNICIPAL THEATER OF BOLOGNA

2.1 *History of the theater*

The Municipal Theater of Bologna is a *unicum* among Italian-built heritage: it is one of the oldest examples of Italian masonry theaters, and it also offers an extensive repertoire of construction techniques from various ages.

Bologna had many public and private theater buildings in the 18th century (Quagliarini 2008). In this context, the Municipal Theater was built to replace the Malvezzi Theater, destroyed by fire in the old town in 1745 (Ricci 1888). The original design was by Antonio Galli Bibiena (1697–1774), who had thirty years of experience as a theater architect at the Imperial Court of Vienna (Ricci 1915). The construction consisted of load-bearing masonry walls and a timber trussed roof. However, because of a great controversy raised by the Accademia Clementina Bolognese and some serious financial difficulties, the challenging project was only completed in 1763. It was downsized, resorting to simpler decorations, smaller stage dimensions, and some construction modifications that brought arly deterioration to the building e (Bergamini 1966; Ricci 1884).

The Theater's deterioration was so critical that many repairs and maintenance works were carried out between 1818 and 1820 under municipal architect, Giuseppe Tubertini (Giordani 1855). The roof of the stage was lifted to host more modern and sophisticated scenery designs, and Filippo Ferrari built a fascinating wooden machine to raise the floor of the stalls, bringing it up to the level of the stage and obtaining a single large hall to host events and costume balls. In 1854, the architect Carlo Parmeggiani restyled the building. Then, in 1866, the engineer Coriolano Monti designed the rear facade in a post-unification style (*Il Restauro del Teatro Comunale di Bologna* 1981). In the late 19th century, new rooms were added, and the heating and lighting systems were adapted to electricity.

After the fire in 1931, which almost destroyed the stage, substantial reconstruction works had to be performed: the previously mentioned reconstruction of the stage tower by the engineer Armando Villa and the main façade arrangement by the architect Umberto Rizzi in 1935. Villa designed a new autonomous reinforced concrete structure, considerably broader and higher than the previous one, adding a piezometric tower for fire safety (Villa 1936).

The last substantial interventions took place between 1980 and 1981 when the oldest parts of the building were restored (Pozzati et al. 1982; Zangheri et al. 1981). Nowadays, the building forms the core of the strategic center in the University area, planned as an artistic and cultural district of Bologna (Figure 2).

2.2 *Reconstruction of the stage tower (1931–1935)*

In November 1931, a dangerous fire almost destroyed the Municipal Theater's stage (Figures 3, 4). Newspapers of the time report that flames ruined only the stage thanks to the iron safety curtain, entirely saving Bibiena's great hall, which otherwise would have been destroyed because of its highly combustible wooden structures (Ricci 1931).

The reconstruction of the stage was considered an opportunity to carry out a series of significant works, such as a new fire safety system and the Theater's

Figure 5. The reconstruction of the stage tower. Donati & Zanichelli Company's private archive.

adaptation to the new technical-artistic needs emerging in that period. A larger space was required on the stage for scenery maneuvering, and a higher covering was necessary so that the top backdrop could be placed at a height not visible to the audience (Ufficio Tecnico del Comune di Bologna 1932). The Technical Office of the Municipality of Bologna drew up a preliminary project, defining the maximum size of the new building, materials, and other essential construction data. Many projects were presented, and a lengthy discussion started about the type of construction to adopt for the new stage. The most cost-effective solution was chosen to improve both the spectators' enjoyment and the backstage maneuvering conditions. The design was commissioned to Villa and the execution to Donati Agostino & Figli company (Ufficio Tecnico del Comune di Bologna 1933a).

Armando Villa graduated in Bologna in 1920 and was fascinated by the emerging reinforced concrete technique; he designed many challenging and daring works during the first half of the 20th century. (Villa 1983). The engineer seemed to have understood the principles and critical issues of the reconstruction project and wrote: "While our entertainment halls are in general perfect for their sonority and aesthetic beauty, the same cannot be said about the stages, which have low overall dimension and are often in wood for the most part. Very high costs are incurred to make them more modern, […] to raise rooms with expensive masonry structures, and to equip them with increasingly improved but at the same time expensive systems" (Villa 1936).

Following his way of thinking, Villa's proposed solution was remarkably valid for the building culture of the '30s. It consisted of reinforced concrete frames that caged existing masonry walls (Figure 5). The first phase included demolishing masonry over 15 meters high, which had been burnt by fire, replacing two old masonry pillars with a reinforced concrete one to make maneuvers easier in the backstage (Ufficio Tecnico del Comune di Bologna 1932).

The design of the roofing system required special attention because of its considerable size. In the 1930s, many innovative solutions for realizing large span roofs at considerable height were presented in the European context. For instance, the Baroni-Lüling patent and the Mélan system used reinforced concrete trusses without adopting expensive temporary supporting wooden structures (Campus 1932; Santarella 1931). Armando Villa analyzed these techniques and proposed his original reinterpretation to build the Municipal Theater's covering-trusses.

3 ARCHIVAL RESEARCH AND SURVEY ACTIVITIES

A cross-analysis was carried out between archival sources (historical photographs, preliminary and executive drawings, reports, structural calculations), geometric information (from the digital survey made in 2019), and photos (from various inspections) to understand the construction peculiarities of the entire building.

The archival research has been conducted in several public archives (Archivio Tecnico Comunale, Archivio Storico Comunale, Biblioteca dell'Archiginnasio, Archivio di Stato), and the private archives of the Armando Villa's heirs and the Donati Agostino & Figli Company (respectively Andrea Villa and Donati & Zanichelli S.R.L.). However, some original drawings could not be examined due to their state of deterioration.

An accurate TLS survey of the Theater's stage tower has been carried out with a *Faro Cam2Focus 3D®* laser scanner. The survey campaign took three working days, and it was necessary to shoot 242 scans. Many high-resolution scans were necessary due to obstacles between the structures, for example, air conditioning systems, electric cables, maintenance walkways, and especially the high number of backdrops hanging from the top of the stage tower. Alignment of scans was made through *Faro Scene 2019®* software. Despite the complexity and occlusions of the surveyed space, it was possible to achieve an extremely accurate alignment.

A large amount of geometric data from the TLS survey allowed the realization of a 3D model in *Rhinoceros®* software (Figure 6). Thanks to the 3D model and the point cloud, it was possible to understand the building dimensional aspects by making direct measurements, extrapolating orthophotos, and moving virtually inside the Theater's rooms.

4 CONSTRUCTION CHARACTERISTICS

Armando Villa made some changes to the original project during both tender and construction phases, which can be grouped into the preliminary design and as-built. While the planning evolution was studied exclusively through archive research, the correspondence between design drawings and the built construction was verified through the field inspections and comparison with the laser scanner survey output.

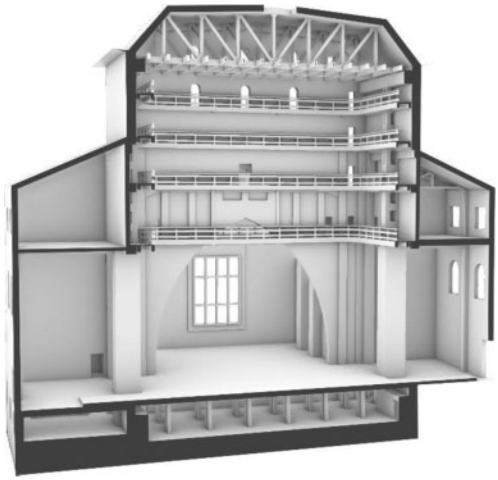

Figure 6. Perspective transversal section of the 3D model of the Municipal Theater's stage tower (© 2020, Beatrice Salmi).

4.1 *Preliminary project*

The reconstruction project faced complex issues for the emerging, but still inexperienced, Italian reinforced concrete technique. These include the connection between the old and the new built volumes, the installation of a large span roof at considerable height, the design of a structure capable of withstanding the heavy mobile loads of the scenography, and ensure very high fire resistance.

4.1.1 *Covering system*

As mentioned, temporary wooden structures, which were usually used to support the construction of reinforced concrete trusses in that period, would have been costly for a span of 25 m and an installation height of 30 m. For this reason, Villa initially intended to use the Baroni-Lüling patent (Villa 1933a). This system provided a semi-rigid metal reinforcement (withstanding the formwork and the service bridges) prepared on the ground and then raised to the support level, avoiding temporary structures. This patent was adopted, for example, for the roof of the Diana Summer Theater in Milan (Santarella 1931). However, Villa considered Baroni-Lüling's reinforcement insufficiently rigid because it was made only of metal rods spaced by bolted plates. So, he decided to adopt a more rigid metal structure using section bars and properly shaped elements to realize the reinforcement of the trusses.

Villa's solution can therefore be interpreted as an adaptation of the Mélan system, which was widespread in Europe since 1892, initially for vaulted ceilings, and later for arched bridges (Barazzetta 2004). This system avoided the construction of slight arches using temporary pillars, using the load-bearing capacity of a metal framework reinforcement made of steel profiles, supporting the formworks. This reinforcement was then incorporated into the concrete with other reinforcing bars, contributing to the resistant capacity (Giuggiani 2016). Another example of the application of the Mélan system in a similar building in Italy is the reconstruction of the Teatro San Carlo roof in Naples in 1928. This project was presented in 1930 at the First International Congress of Concrete and Reinforced Concrete in Belgium (Campus 1932).

It is possible to assume several reasons for Villa's technical choice. First, the tender specifications required a reinforced concrete structure to ensure fireproofing safety. Also, a more rigid rebar structure – which allowed obtaining a higher moment of inertia and a good concrete constraining – could support loads both during the construction and the life cycle of the building. Villa's solution offered the possibility of casting the concrete at the installation height and not on the ground, so metal trusses were lighter to lift than same-sized trusses in reinforced concrete. In this way, it was possible to cope with most of the construction problems: a complex construction site located in the historical center, the structural continuity and the fireproofing of the stage tower structures, and the reduction of vibrations induced by the pull of the theatrical machines.

The calculation reports (Villa 1933a) express the thought with which the engineer conceived the work. At first, axial stresses in rods were computed using the Cremonian-diagram method, assuming hinge constraints at joints. Next, bending stresses caused by purlins at the truss extrados were evaluated. In this case, the joints were considered semi-fixed constraints. The L section bars show the adopted calculation method. It was executed according to three different load assumptions: the weight of the beam during the hardening of the concrete, plus the weight of the formworks and the service bridges (construction phase), the weight of the fully casted beam, including the weight of the roof and lattice boardwalk during the in-use phase, the fully loaded beam, including the weight of the snow and the pull from backstage machines (Villa 1933a).

According to the Italian construction regulation of the time (Regio Decreto-Legge 1932), the calculations took into account the steel strength equal to 1200 kg/cm^2, the concrete bending strength equal to 40 kg/cm^2, and the concrete bending strength equal to 50 kg/cm^2. Tensioned steel elements were dimensioned considering a zero tensile strength of the concrete (Villa 1933a).

Villa proposed two different geometrical solutions. The first consisted of English-type triangular trusses (Figure 7) as required by the tender specifications; the second consisted of a Pratt truss with parallel stringers that allowed improving the space between the timber lattice floor and the roof (Figure 8). The roof design resorted to a new construction system for the Italian territory, where the steel trusses, made with welded steel angles, were coated with concrete, becoming the reinforcement to the final reinforced concrete structure.

Understanding this extraordinary engineering work is possible only by analyzing the site construction

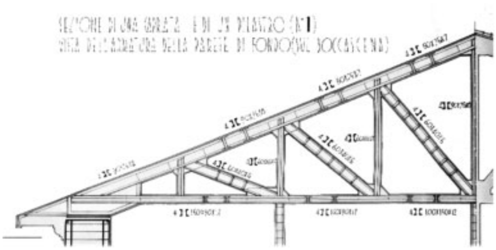

Figure 7. Preliminary solution with triangular trusses. Andrea Villa's private archive.

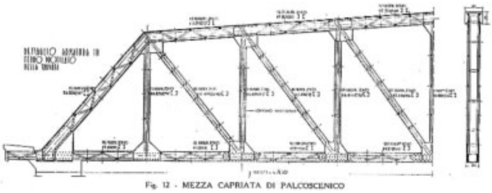

Figure 8. Preliminary solution with polygonal girders. Municipal Technical Archive of Bologna.

Figure 9. The load test of the metal beam. Donati & Zanichelli Company's private archive.

methods and their peculiarities and characteristics. After a load test, the metal beams were assembled on the ground with the formwork (Figure 9). They were then raised to a height of 30 meters by the wooden towers used to lift and distribute materials, anchored on the wall between the stage and the back façade (Figures 10, 11). In this way, the assembly of the trusses could be done simultaneously with the new reinforced concrete frames and the masonry consolidation. Since the balconies' presence did not allow the truss to be lifted as a whole, the two lateral support triangles were lifted in advance, and then the rest of the truss was bolted to them. Once the purlin overhead formwork was assembled, the concrete could be cast. In this way, the trusses were connected by a double ribbing: purlins on top and timber lattice floor at the bottom.

Concerning the roof, its central part was equipped with a large skylight (Figure 12) to create a sort of stack effect in case of fire, carrying away combustion smoke. The Perret system was proposed to protect the hollow brick roof slab from temperature variations that could occur in case of fire. It was made of a double-layer, reinforced concrete slab with an interposed air chamber (Villa 1933b).

Figure 10. The lifting towers of the metal beam. Donati & Zanichelli Company's private archive.

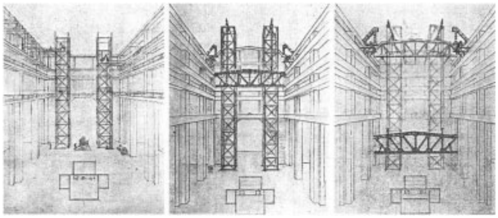

Figure 11. The phases of lifting the metal beams. Municipal Technical Archive of Bologna.

Figure 12. The roof skylight. Donati & Zanichelli Company's private archive.

4.1.2 *Elevation structures*

A new, reinforced concrete frame was designed to cage the existing masonry structure and to raise it. It consisted of pillars, beams, and balconies. The tender specifications required reinforcing some existing pillars and other replacements to make the lateral rooms more easily accessible.

The existing masonry pillars were strengthened with reinforced concrete up to the height of the first balcony through a horizontal edge beam of 30 cm and vertically connected by pillars of 30 × 30 cm, made in adherence to the masonry (Figure 13).

Figure 13, 14. The reinforced masonry pillars. – The pillars with the Vierendeel shape. Donati & Zanichelli Company's private archive.

The new pillars were designed in reinforced concrete. Instead, in contrast to what was initially assumed, they were built of reinforced masonry up to the first balcony level (Figure 13), like the existing ones, to avoid differential subsidence phenomena (Ufficio Tecnico del Comune di Bologna, 1933b).

Over the first balcony, all pillars are raised up to the roof installation height. Due to the significant influence of the wind action, which involves high bending and shear stresses, a rectangular cross-section of 150 × 90 cm was initially dimensioned. A different morphology was adopted during construction since full, cross-section pillars with this size would have been unnecessarily heavy. The new pillars defined an original shape with four external elements tapering upwards, connected by beams, which were shaped according to a spatial "Vierendeel-like scheme" (Figure 14). In this way, it was possible to obtain a high moment of inertia, and a more efficient cross-section, reducing the weight of structural elements (Villa 1933a).

The horizontal connections between the frames consisted of tubular beams measuring 75 × 60 cm, while the top of the pillars was connected, at the trusses level, by a 150 × 105 cm tubular beam. Four balconies contributed to stiffen the structure, made of a 7 cm concrete slab.

4.2 *As-built*

The final project included the demolition of masonry walls higher than 15 meters, burnt by the fire, and the consolidation of the remaining ones, preserved for acoustic requirements. In particular, the wall that divided the stage and the great hall was caged by a reinforced concrete frame, consisting of two pillars of a 60 × 30 cm section, connected by tubular beams of 75 × 60 cm and by the reticular beam of the proscenium. The wall thus behaved as a slab under the action of the wind. A similar intervention was carried out on the wall separating the stage from the backstage, where the ogival masonry arch was preserved (Figure 15).

Figure 15. The consolidation and caging works of the wall. Donati & Zanichelli Company's private archive.

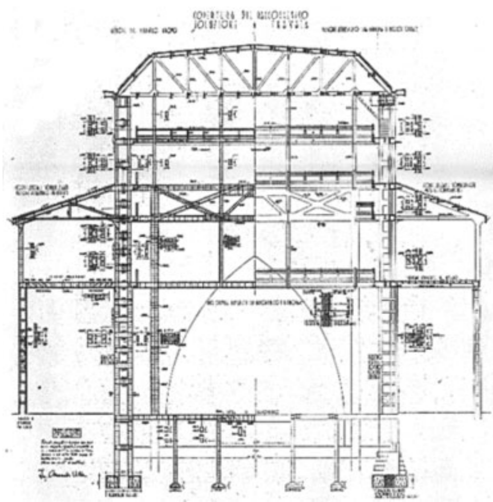

Figure 16. Transversal section of the final project of the stage tower of the Municipal Theater. Covering solution with polygonal trusses. Municipal technical archive of Bologna (Villa 1936).

The preliminary proposal to realize the reticular truss roofing was accepted by the Municipal Administration (Figure 16). Villa designed four identical trusses with a constant spacing to support the roof, and two of them are not supported by an underlying pillar (Figure 17). He tried to connect and stiffen the ring beam at the top of the pillars to guarantee better support to the two mentioned trusses and have an intermediate element to realize the complicated joint between these particular trusses and the Vierendeel-shaped pillars.

Therefore, the frame assumed in the preliminary phase and calculated to withstand the wind action was not built and the final project aimed to exploit the capabilities of the structure differently. Villa tried to give the four walls a monolithic shear wall behavior by realizing stiffening elements in reinforced concrete collaborating with the masonry infill. Three external balconies were built in addition to the elements already

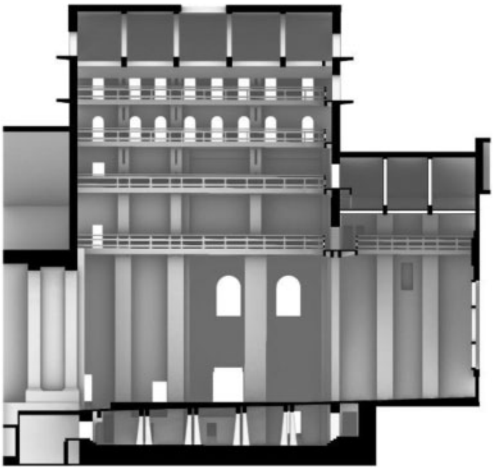

Figure 17. Longitudinal section of the Municipal Theater's stage tower. (© 2020, Beatrice Salmi).

provided (pillars, balconies, tubular beams, and concrete lattice floor beams).The new structure required a continuous foundation, which complemented the existing ones, consisting of isolated elements and masonry arches. Villa reported that once the excavations had been carried out, the existing isolated plinth foundations were slightly modified to create a continuous reversed beam with good cross-section and reinforcement. Subsequently, underground foundation walls were built under all foundation masonry arches and buttresses to merge the existing foundations into the new ones and to consider them supportive and collaborating with the new structure. The final solution adopted for the stage plan was particularly original. Four RC main beams were realized with a mirrored cross-section, parallel to the proscenium. Six pillars in reinforced concrete supported each beam, split in the middle to lower backdrops or other scenery devices along its entire length. Later on, the void between these RC frames was suitably reinforced by a metal crossbar bidirectional frame supporting a wooden slab in the stage. This solution is therefore capable of hosting, for scenery needs, trapdoors, and other scenery artifices.

The engineer also paid particular attention to the fire safety project. First, he adopted design solutions to create a partitioning system acting as a firewall that could isolate any fires on the stage from the room and vice versa. To this end, a new iron safety curtain was installed, and the orchestra pit was made of reinforced concrete. Automatic hydrants and sprinklers were installed as fire protection devices. Two water tanks were built to meet the water demand. The first one was underground, and the second was a hanging tank with 80 m^3 capacity and was designed to ensure enough water pressure. This 44 m high piezometric tower recalls the design of the pillars in the stage tower. It consists of four RC pillars connected crosswise to resist bending caused by wind. Internally the composed pillar is empty to host the boiler smoke duct passage. It rests on a wide foundation base, consisting of two strongly reinforced plates of a one-meter thickness (Villa 1936).

5 CONCLUSION

The importance of the Municipal Theater of Bologna emerges in the field of construction history as well as its cultural and artistic history, bringing to light a hidden chapter in the evolution of reinforced concrete techniques in the 1930s. As it is well known, studies on the subject have usually examined the so-called "exemplary buildings" or "famous designers".

The works carried out by lesser-known designers can instead constitute a new horizon for research, contributing, on the one hand, to confirm the knowledge already acquired, and on the other, to follow new paths to explore the history of the development and diffusion of reinforced concrete.

The work of Armando Villa confirms the Italian trend to combine the new material with solid masonry structures. It also simultaneously shows excellent awareness of the properties of reinforced concrete and some of its limitations. The engineer could combine existing and innovative solutions to meet both the requirements of the tender specifications and the structural, safety, and functional needs that a theater stage tower required.

The documentary, historical research, matched with modern digital survey techniques, made it possible to discover a piece of the Bolognese reinforced concrete history, creating the basis for verifying whether this work influenced theater buildings in the rest of Italy and Europe and vice versa.

Although the adopted solution was designed when reinforced concrete frames were being used in the most important constructions throughout Italy, it shows that this material was mainly used to solve practical construction problems and not to give more relevance to the architectural appearance of buildings. In this case, the reconstruction project aimed to integrate a new structure with existing masonry walls, raising the old structure to create a larger space for scenery maneuvering. Therefore, the reinforced concrete was recognized as the construction technique that best satisfied this purpose.

ACKNOWLEDGMENTS

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