TEMA

Technologies
Engineering
Materials
Architecture

Journal Director: R. Gulli

e-ISSN 2421-4574

Vol. 6, No. 2 (2020)

Issue edited by Editor in Chief: R. Gulli

Cover illustration: The west grandstand of the Flaminio Stadium in Rome, by P.L. and A. Nervi.

Editorial Assistants: C. Mazzoli, D. Prati

TEMA
Technologies
Engineering
Materials
Architecture

e-ISSN 2421-4574
Vol. 6, No. 2 (2020)
Year 2020 (Issues per year: 2)

Scientific Society Partner:
Ar.Tec. Onlus
c/o DICEA, Università Politecnica delle Marche,
Polo Montedago, Via Brecce Bianche 12
60131 Ancona - Italy
Phone: +39 071 2204587
Email: info@artecweb.org- tema@artecweb.org

Media Partner:
Edicom Edizioni
Via I Maggio 117
34074 Monfalcone (GO) - Italy
Phone: +39 0481 484488

TEMA: Technologies Engineering Materials Architecture
Vol. 6, No. 2 (2020)
e-ISSN 2421-4574

Editorial

BRIDGING OVER BRIDGES' SOURCES PROBLEMS

TEMA
Technologies
Engineering
Materials
Architecture
e-ISSN 2421-4574
Vol. 6, No. 2 - (2020)

Tullia Iori

DICII - Dipartimento di Ingegneria Civile e Ingegneria Informatica, Università di Roma Tor Vergata, Roma (Italy)

DOI: 10.30682/tema0602i

To the victims of the collapse of the bridge over the Polcevera river

The collapse of the bridge over the Polcevera river on August 14th, 2018, triggered a profound rethinking of historical research in the field of structural construction. The bridge was one of the most iconic symbols of the Italian School of Engineering.

On the one hand, many doubts about its collapsing modes imposed with increased urgency the scientific effort to study and carry out thorough historical research. On the other hand, the unawareness of the value of the Italian structural heritage, as well as of its construction experimentation, and average age, made its dissemination among students and professionals, who will be involved in its future safeguarding, even more necessary.

A thousand-stages tour de force, which was started to inform everyone about the cultural identity, the technical value, and the historical significance of the School of Engineering, has not prevented a continuous, more private brooding related to the way of carrying out this research, so devoid of historiographic tradition.

Is our approach properly historical research? Moreover, where does the history of structural engineering fit into the broader overview of historiography? In 2005 Sergio Poretti included it in the history of construction, which he defined as the "*material history of architecture*", referring to Eugenio Battisti, who already identified the art of construction as a new frontier in the history of architecture in the 1980s[1].

Nevertheless, Poretti recognized that studies on Italian structural engineering of the 1900s have never been part – or only marginally – of the history of architecture. The truth is that these studies still need an essential interpretative and critical synthesis operation to reconstruct their general framework; it is also true that this synthesis, as consolidated in all the more mature historiographies, must be based on the "slow, patient accumulation of precise surveys and specialist studies". These are tiring, strenuous micro-stories that struggle to find researchers interested in digging them out of the archives.

This is the primary concern about this research. For the usual atavistic problem: the engineer is not interested in history, in the past. He looks forward to the future, to the new.

However, in order to investigate Morandi's or Zorzi's intricate carpentry or Musmeci's high-mathematical relations, it is necessary to have an engineer's education. An advanced education able to distinguish a hinge from a fixed joint, not because it is written in the technical reports but because it is evident from the geometry of the joint itself. The engineer must be able to recognize, in the still handwritten overly synthetic calculation reports, the starting hypotheses, skip the needless passages and understand the rough core of the conclusions. Moreover, the well-trained engineer should resist the temptation of recalculating old structures with modern software, the most useless hobby for a historian (necessary only for those who have to verify and validate the current use – but this is a totally different field) and instead make an effort to read the papers through the eyes of a pre-computer engineer, without evaluating the project through modern parameters. He must, in brief, avoid the actualization typical of the "presentism" that affects traditional historiography as well. At the same time – and this is much more challenging – he has to know all the other histories connected to the construction: those of the materials, of the building site, of the construction companies, but also the political, economic, and social issues of the country where the work has been built.

There are no Degree Courses and related “Dublin Descriptors” for these types of qualifications.

If they did exist, a branch of “Contemporary Diplomatics” would undoubtedly be compulsory teaching. What are the documents we are dealing with in our research? Are they “truthful”, i.e., are they what they claim to be? What do they precisely tell us? The dramatic recent events have required further reflection on this as well.

The historical work I have carried out in the last few years has dealt with peculiar documents that are rarely interesting for other researches. Working to reconstruct the history of reinforced concrete in Italy, I have thoroughly examined, for example, the invention patents archive from its origins to the Second World War. Not searching for a specific patent attributed to a known author, but merely going through all the ones relevant to the construction technique evolution. The history of the material has written itself: and not because the technique was a sequence of inventions but because the variation in density of patents dedicated to specific innovations has made the main stages of the entire process evident.

Moreover, most of the patents were deposited by unknown professionals who have remained so even after the investigation. Above all, in the patents there is no trace of their practical applications since they are often chimeras that are almost unachievable. Houses hanging like cloths from laundry threads – and therefore potentially unshaked by earthquakes – or hollow blocks for floors shaped like puzzle pieces, that should become resistant to tensile stress, even without rebar reinforcement. Nevertheless, from a statistical point of view, they provide a clear overview of the current debate and, therefore, the evolutionary path of the materials.

This is not the only reason for which the patent is a peculiar document: the important ones, in fact, decisive for the history of the Italian School of Engineering, those of Nervi, for example, hide more than explain, generalize instead of specifying, since the patent is intended to protect rights instead of providing instructions to those who want to copy the idea. However, for the construction historian, the patent is a “sound” document.

Other documents that crowd this research field are the official documents, protocolled, perhaps registered at the Court of Auditors. In order to find the dusty file of a contract or a test certificate, we are willing to crouch uncomfortably, in a semi-abandoned dark archive, next to a dead mouse.

Yet the 122 pages of the “Report, minutes of visit and test certificate” for the construction work on the 24^{th} parcel of the Genoa-Savona motorway, two and a half kilometers long and including the bridge over the Polcevera, report that, compared to the contract signed in September 1961, when no one had even imagined how to build the cantilever brackets for the balanced trestles, the only project variants would have involved the use of half-inch strands instead of the 7mm cable initially planned for all prestressing operations. A few well-calibrated sentences by which the commission relieves itself of all responsibilities for the execution changes made on-site concerning the 20 preliminary drawings attached to the contract, while the final drawings would be over 400! The testing certificate has a completely different institutional scope, not that of explaining to the historian what truly happened during construction.

One more example: the drawings attached to the contract for the construction of the Risorgimento bridge had already been utterly outdated upon signing. The designer Hennebique and the Porcheddu company, in October 1909, were already working on a new and completely different project but could no longer delay the signing. Is that “contract” a fake indeed? Of course not: the amendment during construction is a constant in our databases, but whichever researcher found only those drawings (and not those that were later realized, but which would never be validated by any formal signing) could completely misunderstand the real conception and behaviour of the bridge.

There is another typical problem we are dealing with in this research: sources may have been filtered. Not necessarily what we do not find in an archive has never existed.

This is especially true for the queen of sources, the one that makes our eyes blink the very instant we find it, but which we ought to take with a grain of salt: the building site picture. It seems a contradiction: the photo or video of the building site, when fortune shines, would seem the most incontrovertible proof of the way the work was built. Nonetheless, even the well-stocked collection can hide rather than show.

The digital scan of about 500 photographs representing the bridge construction site over the Polcevera are archived in the SIXXIdata: more than 250 of them, from the Condotte company's archive, linger from all perspectives on the temporary tie rods and the thousand work equipment – from the harp for the temporary deck prestressing to the cast-in-place form traveler – which are absent in the drawings. Nevertheless, the day after the collapse, some American newspapers published a series of photos by Mario De Biasi, extracted from their huge database, and dated August 1967. The photojournalist authored a few very famous shots, as "Gli italiani si voltano" (*Italians turn around*) and made reportages for the weekly magazine "Epoca". De Biasi reached the 9th pile early in the morning, dangerously climbed the stay, and reached the top of the antenna. Was he authorized or helped by someone, who knows? From up there, he took some unrepeatable images that document the construction site one month before the inauguration. Five of those photos were then published in the August 13th, 1967 issue of the magazine. One important shot is missing; the one that at the deck level shows a handsome worker, striking a pose while working on one of the stays of the 9th pile, just the stay that broke first. In the foreground, we can see a sheet metal cover wrapping the half-inch strands, which in the executive drawings are prescribed to be sheathed one by one. No document talks about this cover, no update of the drawings refers to this detail, no calculation considers this modification in progress.

Our photos skip from July 7th directly to ribbon-cutting by Giuseppe Saragat on September 4th: as if there was nothing to be documented in those two months of final acceleration of the construction site.

In short, the sources are "traces that the past has transmitted to the present and that we, therefore, find in the present"; they are not all we would like to know. And for the rest?

In the case of Polcevera, unfortunately, we have the autopsies of the bridge – the thin sections of exhibit 132 – which allow us to discover today all that has not been documented. However, we would obviously have all preferred that the bridge was still in place, perhaps after careful and timely maintenance that could have extended its life for many decades.

For all other chances, Manzoni explains: "*la Storia è costretta a indovinare. Fortuna che c'è avvezza*" ("it is a fact that History is doomed to guess everything. Luckily enough, it is used to that")[2].

Notes

[1] Poretti S (2005) Storia delle costruzioni e storia dell'architettura. In: Teoria e pratica del costruire: saperi, strumenti, modelli. Edizioni Moderna, Ravenna, vol. 1, pp 25–30.

[2] Manzoni A, *I promessi sposi*, cap. XIII.

“STRUCTURAL FANTASIES” IN 20TH CENTURY ARCHITECTURAL HERITAGE: THE FORGOTTEN WORKS OF ENRICO CASTIGLIONI

TEMA
Technologies
Engineering
Materials
Architecture

e-ISSN 2421-4574
Vol. 6, No. 2 - (2020)

Ilaria Giannetti

DOI: 10.30682/tema0602a

Highlights

This article focuses on the design process and construction history of the most significant works of the engineer and architect Enrico Castiglioni (1914-2000) that were built between 1950 and 1965 in Italy’s Varese territory. The survey aims to provide fundamental knowledge for their appreciation in the context of 20th century architectural heritage and for the implementation of future tailored preservation strategies. The design- and construction-related analyses are based on local archival documents and the combined sources of the literature of the time.

Abstract

During the 1950s, the “made in Italy” reinforced concrete structures established itself around the world. As a consequence, fascinating Italian architects turned structural- and construction-based research into novel figurative conceptions. Enrico Castiglioni (1914-2000) was a distinctive interpreter of this collective phenomenon, but, although his work was significantly discussed in the literature of the 1950s and 1960s, it is today completely neglected. This paper presents construction-history surveys, providing a historical and technical narrative of Castiglioni’s built work.

Keywords

Enrico Castiglioni, Construction history, 20th Century architectural heritage, Reinforced concrete, Italy.

Ilaria Giannetti
DICII - Dipartimento di Ingegneria Civile e Ingegneria Informatica, Università di Roma Tor Vergata, Roma (Italy)

** Corresponding author:
e-mail: ilaria.giannetti@uniroma2.it*

1. INTRODUCTION

In the 1950s, when large “made in Italy” reinforced concrete structures became icons of structural engineering and when Italian engineers established themselves worldwide as master builders who developed expressive languages through construction innovations [1, 2], a sort of “structural imagination” spread through modern Italian architecture [3, 4]. Meanwhile, even beyond Italy’s borders, “structuralism” in architecture (defined as an actual structural tendency embodied by reinforced concrete) established itself as a global trend in the modern movement to devise functionalist architectural forms [5–7].

In this context, the Italian engineer and architect Enrico Castiglioni (1914-2000) joined the dialogue with a series of projects – for the most part unbuilt “structural fantasies” – that received consistent attention in the technical literature of the time and the international discourse of architectural structuralism. The first main publications of Castiglioni’s work, in the mid-1950s, were related to the 1954 Italian design tender for the new Naples central railway station [8]. In his attempt to illustrate the particular structural body of the presented design, Castiglioni produced an impressive series of images of a physical model representing the free-form, reinforced concrete vaulted roofing of the station building. These images were appreciated by the influential Italian architect and critic Bruno Zevi (who was involved in the same tender) and they were printed as the cover image of the first issue of his architectural journal, *L'Architettura: cronache e storia*, dated June 1955 [9]. Thanks to the "structural tendency" that was informing the architectural discourse, the iconic image made possible the dissemination of Castiglioni's work to the international scene through a series of monographs published in a wide range of international technical journals [10–12].

In 1960, in the first edition of his essay *Strukturformen der modernen Architektur*, the engineer and critic Kurt Siegel included two unbuilt structures designed by Castiglioni. Characterised by an unusual "structural accomplishment of spaces of great architectural significance", the two projects were listed in a world ranking of the most attractive structural architecture of the time [13]. On 5 April 1962, even Ernest Neufert took his students to visit a construction site of Castiglioni's work [Castiglioni Private Archive, Letters, E. Neufert, 1962]. In 1965, the critic Udo Kultermann chose Castiglioni's 1959 design of the Istituto Tecnico Industriale Cipriano Facchinetti school building as the cover image of his book *Neues Bauen in der Welt* [14]. Then, in 1967, Castiglioni's work was included (with a dedicated headword) in the first edition of the *Dictionary of Architecture* by Jhon Fleming, Hug Honour, and Nikolaus Pevsner [15]. This tribute of international criticism faded over time and disappeared by the 1980s [16]. In 1979, the editors of the

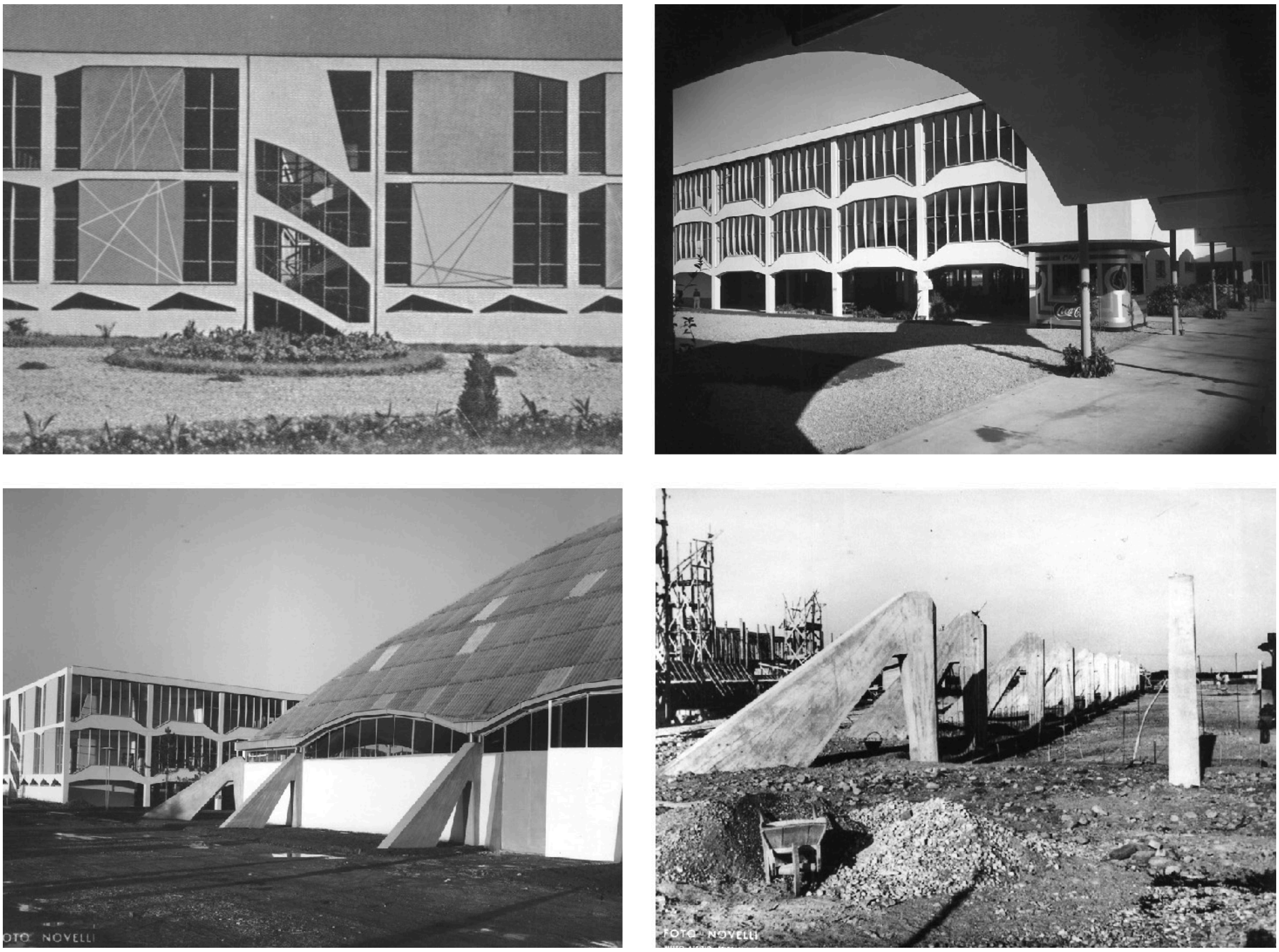


Fig. 1. ˝Mostra Internazionale del Cotone e del Rayon˝ *building in Busto Arsizio, 1951-1954, demolished in 2015. From the top and from left to right: external views of the buildings and construction site of the main vaulted pavillion (courtesy of Castiglioni Private Archive).*

magazine *Domus* organised the exhibition *28/78 Architettura*, showcasing fifty years of architecture in Italy [17]; Castiglioni's work was considered in a monograph alongside the work of Nervi, Mangiarotti, Mollino, Mollino, Moretti, Ponti and Scarpa. After this last acknowledgement, Castiglioni's work was gradually forgotten, and no complete, dedicated retrospective has yet been produced [18–20]. (As material proof of this historical neglect, in 2015, the complex of the Mostra Internazionale del Cotone e del Rayon in Busto Arsizio (Fig. 1), dated 1952-1955 and considered irreparable due to a lack of maintenance, was demolished, removing all evidence of the original structure of Castiglioni's most impressive work without any acknowledgement of its technical and historical value). In this context, the following pages analyse the design processes and construction histories of Castiglioni's most significant works, illuminated by the literature of the 1950s and 1960s [10–17]. These surveys, based on the literature of the time and local archives (Castiglioni Private Archive, Busto Arsizio, and Gorla Minore Municipal Archives, Varese State Archive), provide foundational knowledge for the cultural appreciation of Castiglioni's heritage and tailored preservation strategies for his buildings currently in use.

2. THE "STRUCTURALIST INFERENCES": FIRST WORKS (1950-1954)

Castiglioni was born in 1914 in Busto Arsizio in the province of Varese. After taking his first degree in civil engineering at the Polytechnic of Milan (1937) and qualifying for the profession of architect in Rome (1939), he concentrated almost all his professional activity in the land of his birth. In the post-war period, the self-sufficient development of the provincial territory, directly governed by local engineers and architects, guaranteed him a continuity of work that, between the early 1950s and the mid-1960s, engaged him in the construction of buildings for the development of the collective life of small municipalities (churches, sports facilities, and primary schools). At the same time, he participated in a long series of design competitions in which his most celebrated "structural fantasies" took shape [10–15]. As noted in the first monographic review of Castiglioni's architecture (in the December 1955 issue of *L'Architettura: cronache e storia*), his first works displayed an evident "ease in inventing structures" [10].

Castiglioni's first built work was an expansion of the Rosetum institute in Besozzo (1950). In the design of the complex's new chapel, the concept of the internal space was characterised by the contrast between two structural systems: a corrugated shell roof and a beam-and-pillar frame. The roofing shell comprises a series of ten round transverse vaults, three meters in diameter, made of eight-centimetre-thick prefabricated brick arches set on reinforced concrete bond beams. The succession of the vaults, defined by Castiglioni as a "folded but never rigid sheet structure" [Castiglioni Private Archive, Rosetum, Technical Report, 1951], therefore rests on the longitudinal beams that run parallel to the perimeter walls and connect to the pillars, forming an autonomous frame (Fig. 2).

Fig. 2. *Rosetum chapel in Besozzo, 1950-1951. Interior views (courtesy of Castiglioni Private Archive).*

The same combination of two structural systems (the thin vault and the exposed frame) was developed, with original results, in the enlargement of the sixteenth-century church of Viggiù (1952), consisting of a new rectangular hall (eight by twenty meters) with small side rooms. The spatial conception of the hall is based on the combined use of a thin, sinuous, reinforced concrete vault with ten hefty tripartite supports (inverse tripods). Seen from the front, each inverse tripod, originating from a single support on the ground, consists of a vertical and flared central pillar and two inclined and tapered lateral arms that extend outwards, forming a V-shaped support (Fig. 3). Thus, if we imagine a transverse section of the structure, the central pillar of the tripod, because it remains detached from the perimeter wall, rises vertically (up to 7.25 meters) to the springer of the central vault while the two arms tilt outwards until they re-join the perimeter wall. On the one hand, the sequence of V-shaped supports constitutes the lateral support of the system of prefabricated brick arches that define the wavy edge of the perimeter wall above and the roof of the side rooms. On the other hand, the central pillars join the thickest sections of the undulating vault characterised by longitudinal reinforcement, forming the stiffening system of the roof. In terms of spatial conception, the combination of robust tripods and the thin vault is marked by the placement of large windows that allow a diffusion of light, which grazes the roof curves and underlines the figure of the "strictly static membrane" [10] devised by Castiglioni.

A data comparison of the original drawings of the vault's contour lines (Fig. 3) with construction site pictures showing the complex curvilinear wooden ribs placed to support the cast-in-place roof (Fig. 4) discloses the modular conception of the vault. A single bay between two tripods was designed as a combination of simple geometric sectors: a barrel vault, a small, lowered dome, and a saddle surface between them. The juxtaposition of the vault sectors in each bay with the overall composition of the four bays is thus indicated by the positioning and shaping of the reinforcements; the domes are characterised by circular reinforcements while the stiffening sections of the roof are marked by major transverse reinforcements. A 3D model analysis (Fig. 4) confirms the efficient modular conception of the apparently free-form vaulted geometry, deepening the interpretative understanding of Castiglioni's design approach [13, 17], and the refined carpentry of the impressive wooden centring confirms the artisanal inner construction of the structure. As soon as the Viggiù building was completed, Castiglioni committed to the 1954 competition project for the Naples station, in which a pattern of thin vaults spanning twenty-five meters and anchored on monumental inverse tripods forms the impressive roof of the station building (Fig. 5). If the affinity of the station building with the structure designed for the small church is evident even when looking only at pictures of the physical model, the present analysis, retracing the similar modular composition of the free-form vaulted roof [13], reveals in the

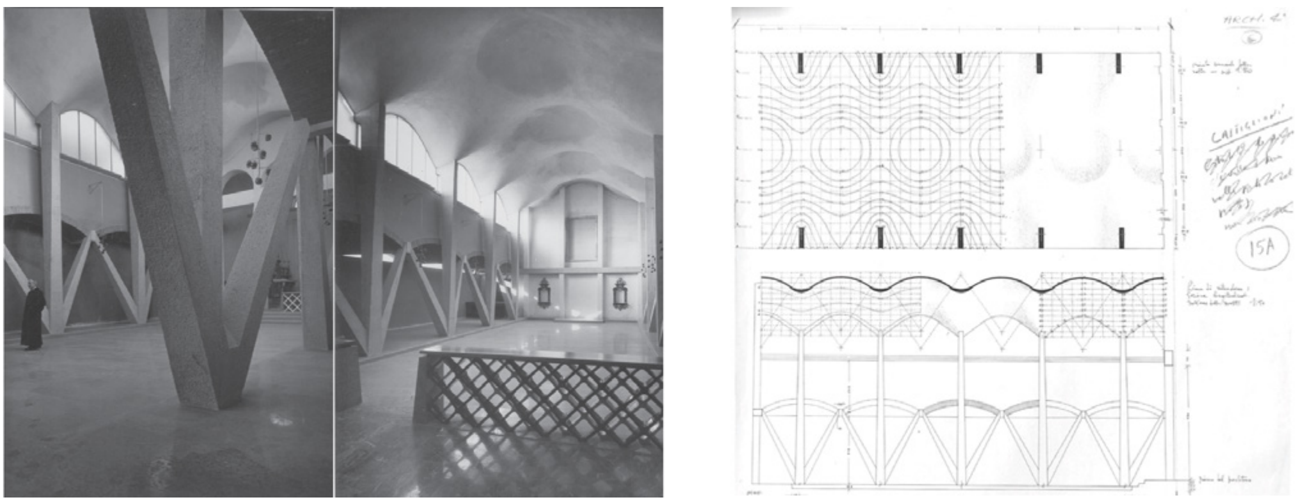


Fig. 3. *Viggiù church, the new chapel, 1952-1953. From left to right: interior view and drawing for the geometry of the vaults (courtesy of Castiglioni Private Archive).*

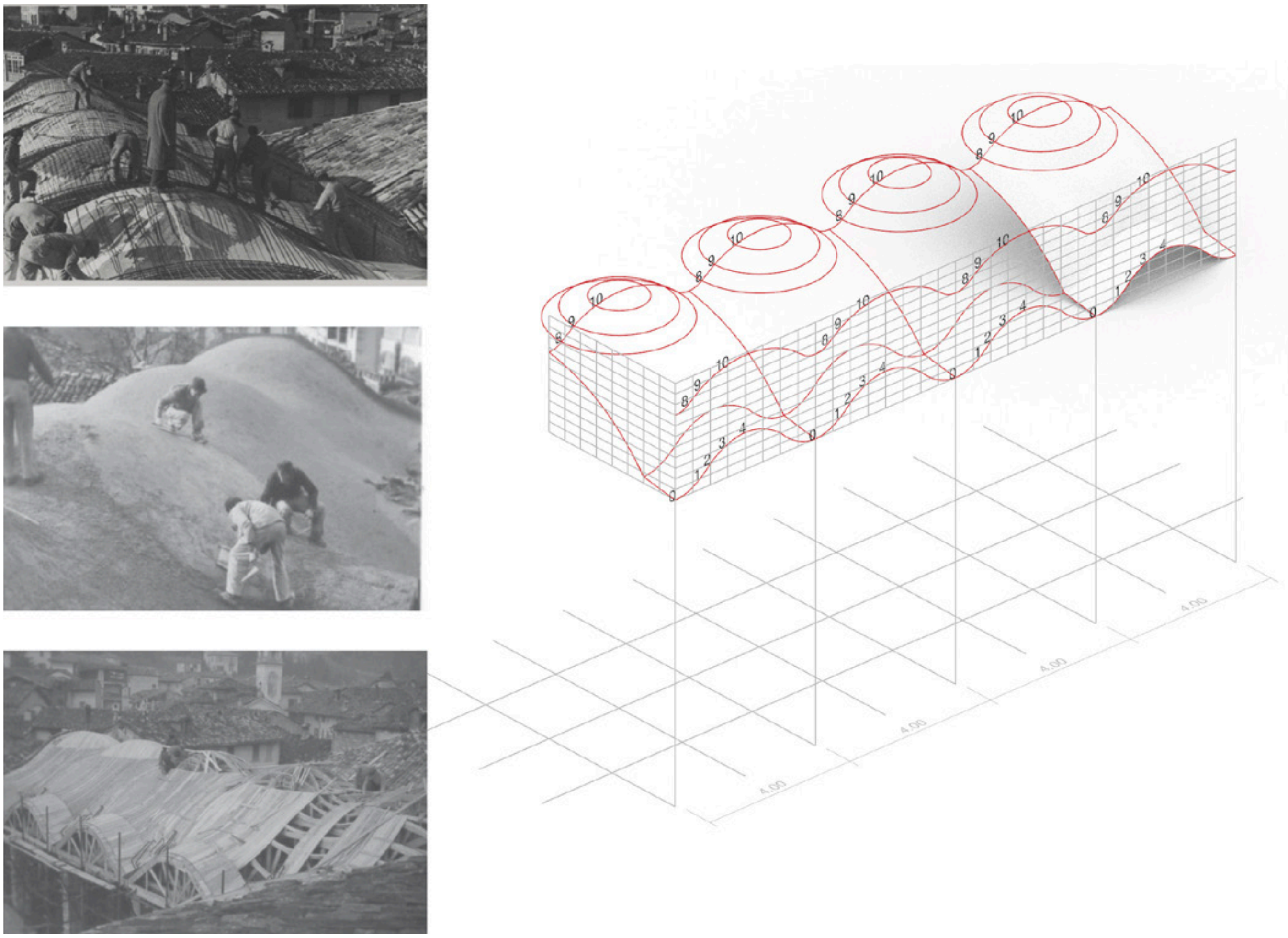


Fig. 4. *Viggiù church, the new chapel, 1952-1953. From left to right: construction site pictures (courtesy of Castiglioni Private Archive) and 3D study of the vaults geometrical conception (the author, 2020).*

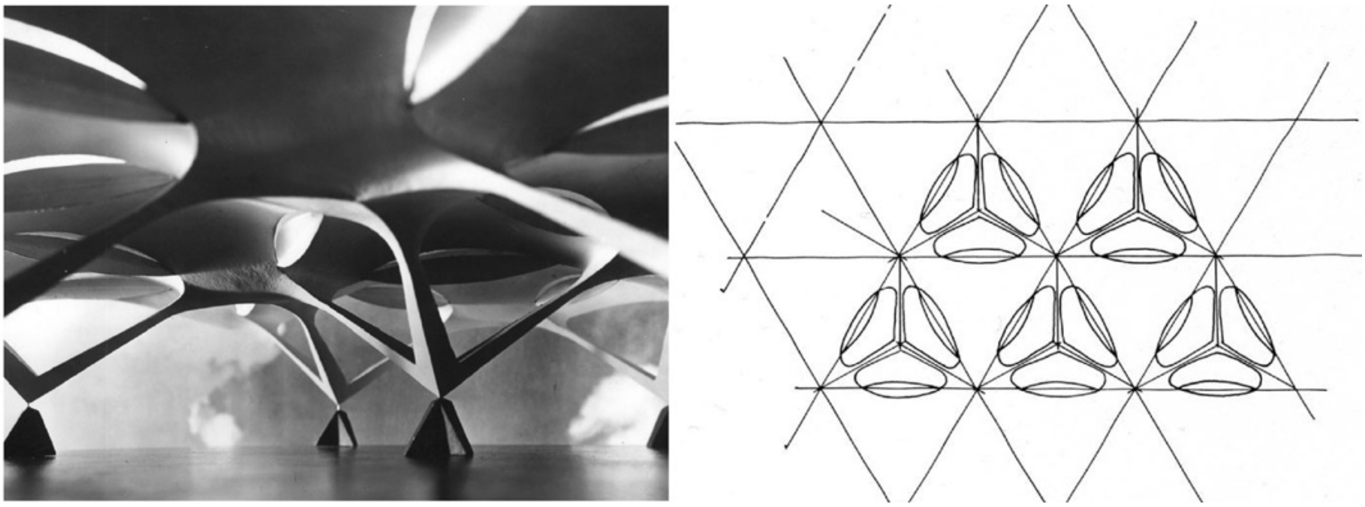


Fig. 5. *Napoli station competition design, 1954. From left to right: picture of the study model (courtesy of Castiglioni Private Archive) and sketch, by K. Siegel, explaining the modular-based design approach [13].*

neglected church hall a miniature-built prototype of the celebrated Naples structure.

In 1953, Castiglioni was commissioned to design the *Casa della Cultura Cattolica* (House of Catholic Culture) in Busto Arsizio. The small, two-story building is characterised by a mixed frame in reinforced concrete and granite [10], conceived by Castiglioni and calculated by the engineer Alberto Cugini. The structure,

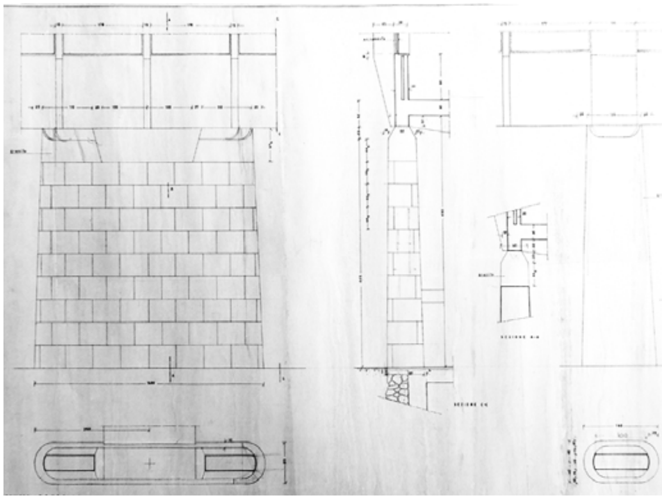



Fig. 6. ˝Casa della Cultura Cattolica˝ *building in Busto Arsizio, 1953-1955. From left to right: façade view and study drawing of the granite pillars (courtesy of Castiglioni Private Archive).*

although of "orthodox conception" [Varese State Archive, Prefettura, Casa della Cultura Cattolica, 1953], has a continuous overhang on the road-facing front of the building, supported at the ends by two sturdy brackets and, in the intermediate areas, by two sturdy granite pillars, the first monolithic and the second, made of reinforced concrete, covered with the same Quasso stone (Fig. 6). A series of reinforced concrete slats, resting on the granite pillars, marks the façade of the projecting body; the front of the structure, as it was conceived, was described by Giancarlo Ortelli with the term *decorazione-struttura* [10] to indicate the figurative use of the structural elements, that affected the pure relation between the shape and structural function. Even Zevi mentioned the small building for its "structural inferences" [5].

3. "STRUCTURAL DECORATIONS" (1955-1958)

Ortelli's definition is also consistent with an analysis of the works of the immediately subsequent years; original structural decorations tried out in the *Casa della Cultura Cattolica*, were developed in two primary school projects built between 1955 and 1959 in Busto Arsizio [21] and Gorla Minore [22].

The first building, designed with the engineer Dante Brigatti (director of the technical office of Busto Arsizio municipality), is in fact recognisable by the design of two original portals, in the shape of a Greek P, located outside the main classroom façades (Fig. 7).

These elements – eight meters high, with a five-meter span and 3.75 meters of symmetrical overhang beneath a sturdy honeycomb frieze – are characterised by a general over-dimensioning with respect to their structural function. The portals, designed as double overhanging frames hinged at the base, support only the 6.25-meter roof spans of the classrooms. The structural dimensions were, in fact, defined as "architectonic" in the calculation model in which it was also determined to disregard the horizontal beam bending moment decrease due to the contribution of the side overhang [Busto Arsizio Municipal Archive, Primary School in Rione Sempione, Technical Calculation Reports, 1955]. From a design perspective, while the dimensional evidence heightens the architectural expressiveness of the portal, the shape evokes its real structural behaviour, announcing itself as a *decorazione-struttura* [10]. Under the weight of the sturdy frieze, the stringer of the portal inflects, and the pillars, still imagined as though they were free at the base, consequently open outwards to where the two sturdy plinths absorb the horizontal forces, keeping the system in balance. All the elements were cast in place as the price of labour was competitive at that time in the Varese district, even for skilled workers (a carpenter or blacksmith cost 408 lire per hour), which made possible the economical formation of "pillars, beams and any reinforced concrete element of any section and shape" as well as the tailored

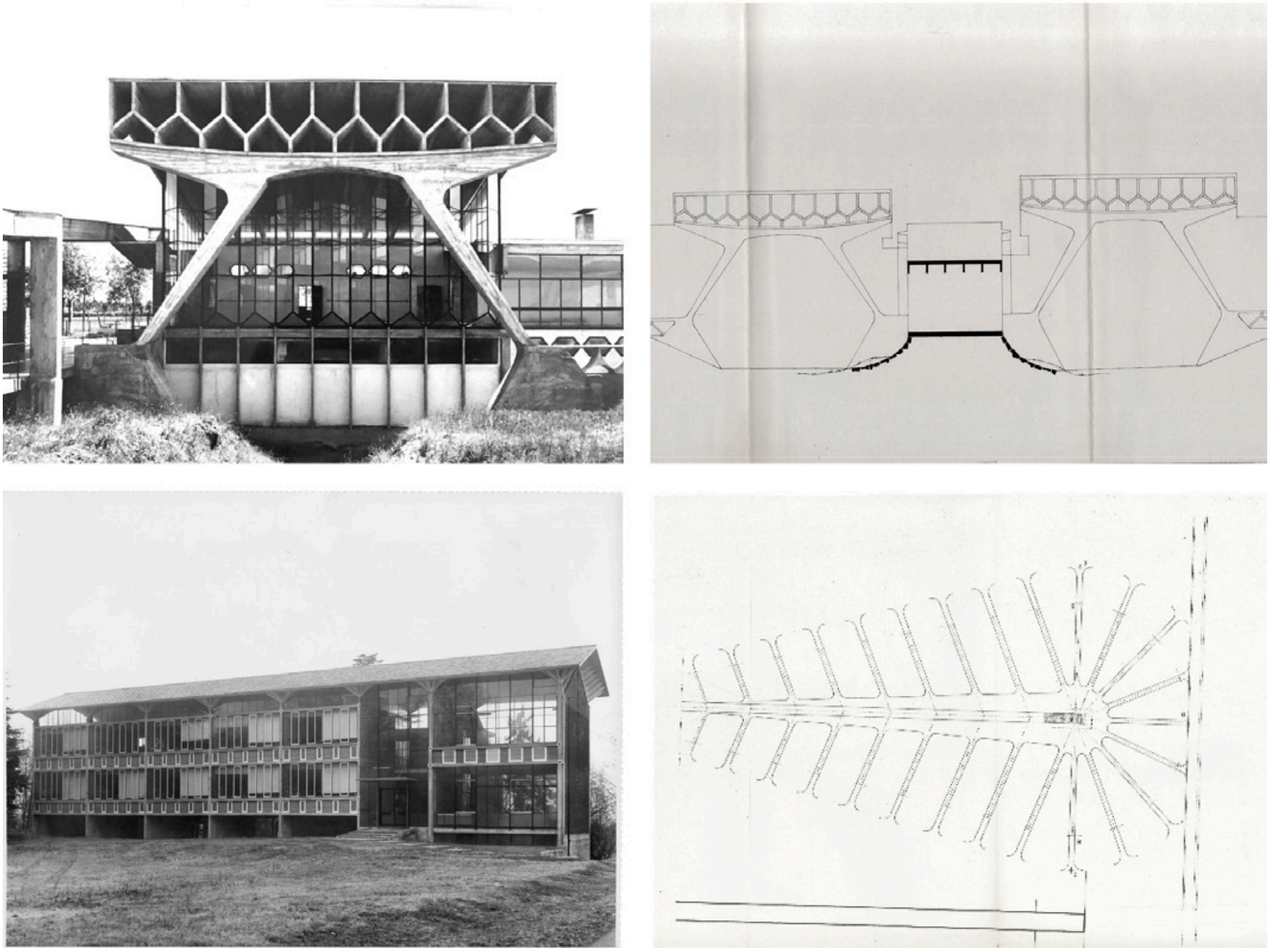


Fig. 7. *Busto Arsizio primary school in Sempione district, 1955-1958. From left to right: view and drawing of the main façade (courtesy of Castiglioni Private Archive); Gorla Minore primary school in Parco Durini,1956-1959. From left to right: external view and crowning detail drawing (courtesy of Gorla Minore Archive).*

designs of the iron-profile window and door frames [Busto Arsizio Municipal Archive, Primary School in Rione Sempione, Technical Prices Report, 1955].

A similar use of structural decoration characterises the primary school project commissioned to Castiglioni by the municipality of Gorla Minore in 1956 [20]. The project, to be carried out in the eighteenth-century park of Villa Durini, was subject to the preliminary requirements and approval of the Superintendence, including the need to favour the perception of the slope of the park towards the valley, to make the outer walls of "selected bricks" and to give the façade "noble decorative elements". The suggestions, accepted by Castiglioni, were applied in the original concept of the building's structure. Eight large, load-bearing walls, in a comb-like arrangement according to the direction of the slope of the park, formed the elevated structure, allowing the body of the building to be traversed physically and perceptually.

A continuous brickwork texture, framed by a reinforced concrete structure, ennobled the load-bearing walls on the transverse façades, repeating itself in the atrium, and a genuine decorative element was designed as a crowning structure (Fig. 7): eight lamellar flower capitals, at the load-bearing walls, partitioned the façade in a large-scale order and became the crowning cornice of the transverse façades and the atrium. Castiglioni intended that the frieze and capitals would be part of the roofing system, as conceived in a first draft that involved extending the design of the flower capitals into a thin, variously curved ribbed shell that remained unbuilt.

4. "SYMPATHY FOR REINFORCED CONCRETE": LAST WORKS (1960-1964)

In 1961, with the support of the influential Italian architect Gio Ponti, Castiglioni was commissioned for the project of the parish church of Prospiano in Gorla Minore. The church, in the shape of a basilica, is characterised by compact external stereometric and marked by a gable roof and by the fusion, in the internal space, of three naves in a single vaulted inner space characterised by a combination of opposing calottes associated with the conduct of liturgical events (Fig. 8). The structure features a thin barrel vault system and a load-bearing roof frame system. As detailed in the reinforcement drawings, the overlapping of the two structural systems created a design that was now far from the explicit structural compositions of the 1950s [13].

That Castiglioni's "structural visions" were no longer adequately supported in the early 1960s by building experimentation (which had constituted the necessary design training at the beginning of the previous decade), is also shown in the results of the A.I.T.E.C (*Associazione Italiana Tecnico Economica del Cemento award*), reserved to works in reinforced concrete, for which Castiglioni competed in 1962, earning only a special mention by the jury. "The natural sympathy that Castiglioni enjoys for reinforced concrete", which inspired the publication of a long story about the mostly unbuilt designs in the journal *L'industria Italiana del Cemento*, cannot compensate for the obvious shortcoming of the construction [23, 24].

Castiglioni's last works date, prematurely, from the mid-1960s. A last major construction site was the im-

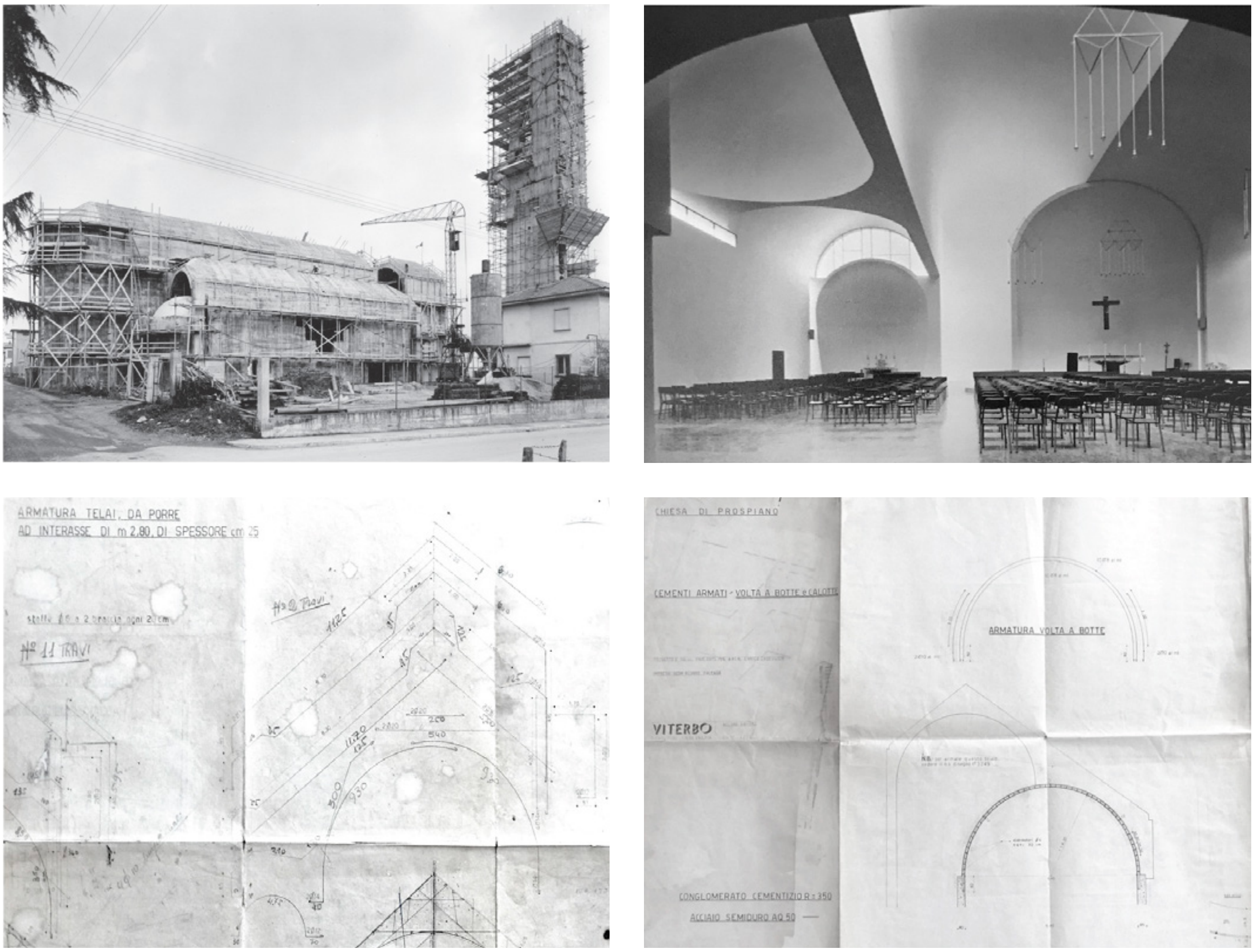


Fig. 8. *Prospiano Church in Gorla Minore, 1959-1965. From the top and from left to right: construction site view, interior view, cross-sections with reinforced concrete reinforcements details by the engineer Viterbo (courtesy of Gorla Minore Archive).*

posing *Istituto Tecnico Industriale Cipriano Facchinetti* (ITIS) school building in Castellanza. Designed in 1959 and constructed between 1962 and 1966 with the support of the engineers Carlo Fontana and Oreste Viterbo, the complex is Castiglioni's most impressive (and well-known) work. It consists of two symmetrical buildings that flank the porticoed atrium; the two buildings have a novel inverted T-section in which the highest central core, split longitudinally by a zenithal fissure, connects to two lateral wings with a curvilinear roof (Fig. 9). A system of reinforced concrete vaults and reinforced brick elements is combined in a rigorously modular approach with an imposing reinforced concrete frame characterised by curvilinear elements. Each half of the building has an independent structure, and the roofing of the central core comprises cantilever-reinforced concrete beams supporting prefabricated brick arches. The half-building structure is composed of four base modules, each of which is formed by three imposing frames in a comb-like arrangement supporting four reinforced-concrete conical vaults that cover the laboratory spaces on the ground floor and the frames of the building's three classroom floors [Archivio Privato Castiglioni, Study model of the building structure, 1960].

The school was completed in 1966 and, due to its impressive reinforced concrete structure, was soon recognised as an icon of architectural Brutalism [14, 15], although the original design of the building, significantly modified to accommodate economic constraints in its construction, would probably have inspired a different critical interpretation. Indeed, the school building was built in two phases, between 1962 and 1966, when the labour conditions in the Varese province had drastically changed. The

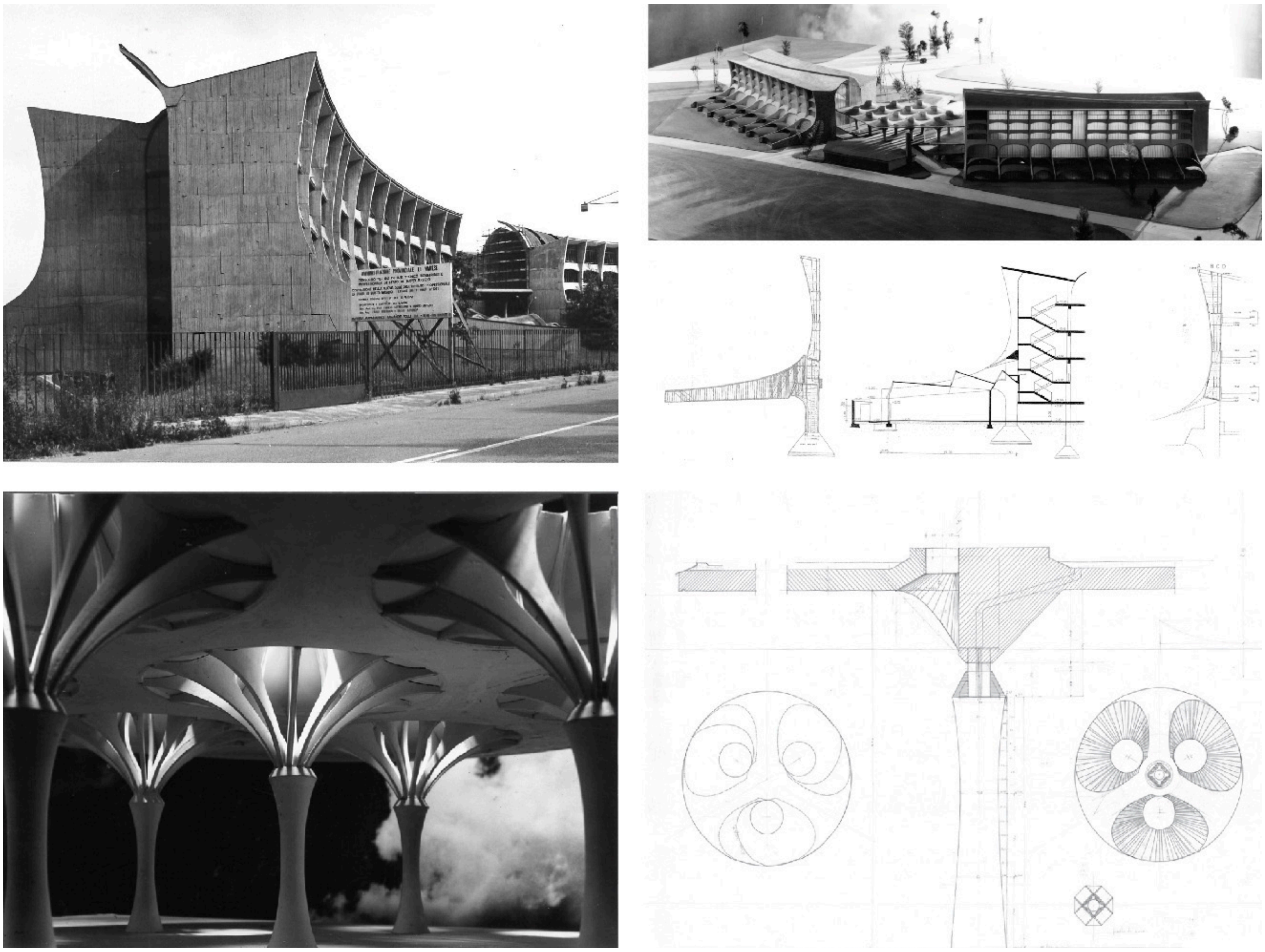


Fig. 9. *ITIS school in Castellanza, 1959-1966. From the top and from left to right: external view, study model and structural drawings by the engineer Fontana (courtesy of Castiglioni Private Archive); study model of the original design and drawing of an intermediate design hypothesis of the unbuilt pillar-skylight of the atrium (courtesy of Castiglioni Private Archive).*

cheap labour exploited for the primary school buildings of Busto Arsizio and Gorla Minore was no more, leading Castiglioni to abandon, during construction, the main "structural decorations" imagined in the original design.

In that design, a pillar-skylight, consisting of shaped slats on a conoidal volume, would have formed the floral ceiling of the porticoed atrium (Fig. 9). With a fully examined construction process relying on the use of special plaster formworks, the element would have been built through the off-site construction of the shaped slats, which would have been set in place without any scaffolding. In 1962, the structural object was drastically simplified to be cast in situ in a novel economic solution; by completely renouncing the pillar function of a skylight, the atrium roofing was set on a new series of completely filled conical calyx capitals. Even the coloured marble envelope that would have partially covered the exposed reinforced concrete of the external façades was eliminated in construction and only the design of the windows frames was built as originally designed, giving evidence of the original decorative conception of the whole [Castiglioni Private Archive, ITIS, Technical Reports, 1959]. The window frames, all made of FerroFinestra profiles and using the cheapest glass panes available on the market, saturate the entire space between the reinforced concrete frames. In the transversal façades, windows over twelve meters high are supported by a spatial reticular structure formed by four trusses, which are connected by a series of tie rods and arranged in decorative framed buttresses to absorb high wind loads. The Istituto has been extensively refurbished in recent years with the replacement of most of the original windows frames and with a white

Fig. 10. *Gorla Minore primary school after original windows frames refurbishment in 2016 (photo by Schüco company, courtesy of Gorla Minore Archive); Busto Arsizio Primary school in 1958 (Courtesy of Castiglioni Private Archive) and after windows original frames demolition (photo by the author, 2019).*

covering on the exposed reinforced concrete, testifying to the lack of historical and technical knowledge of Castiglioni's work among those in charge of the institution.

5. CONCLUSIONS

The present study of Castiglioni's built works provides the first material narrative of this overlooked building heritage of the Varese district. The surveys improve awareness of the 20th century Italian architectural heritage by telling a still neglected local story while also providing fundamental knowledge for tailored preservation interventions to correct the antithetical approaches taken by the institutions in charge (Fig. 10).

In this framework, the presented analysis of construction history led first to project- and construction-related consideration of Castiglioni's work, adding further perspective to the interpretations presented in the literature [17–19]. By referring necessarily to future surveys (currently being conducted) of the unbuilt projects, the analysis shed light on a rigorous, modular-driven design in which historical structural typologies (such as barrel vaults, sail vaults, and domes) overlap with reinforced concrete structural elements (such as frames and saddles) in clear, geometrical compositions. Furthermore, the non-ideological use of construction technology was underlined in the transition from the design conception to the edifice. The combined use of prefabricated brick elements, site-cast reinforced concrete structures, ad hoc designed wooden formworks and off-site produced structural elements supported by metal or plaster formworks as well as the tailored design of iron elements disclose a pure, craft-driven approach grounded on the proximity of the skilled artisans of the Varese territory.

From the perspective of applied preservation, the foundational material knowledge obtained in this study suggests the adoption of tailored interventions for buildings currently in use. The detailed documentation available in the local archives, as disclosed by this research, makes possible a base level of technical knowledge related to architectural, structural, and building material details (Fig. 11).

Works	dates	Castiglioni Archive	Municipality Archive	Varese *Prefettura* Archive	Ap	Sp
1	1950-1951	AD/DR/Pfb	/	/	Ld	/
2	1951-1953	AD/Pfb/Pcs	/	TR/MT	C	C
3	1951-1953	AD/Pfb	AD/TR	TR/MT	C	C
4	1950-1951	AD/DR/Pcs/Pfb	/	/	C	Lm
5	1955-1959	AD/Pcs/Pfb	AD/SD/DR/TR	/	C	Lm
6	1956-1959	AD/Pfb	AD/SD/DR/TR	/	C	Lm
7	1959-1964	AD/Pfb	AD/SD/DR/TR	/	C	Lm
8	1959-1964	AD/SD/DR/Pcs/Pfb	/	TR/MT	C	C

LEGENDA

Works		Archival documents		Abbreviations	
1	*Rosetum* in Besozzo				
2	*Mostra del Cotone e del Rayon* in Busto Arsizio (demolished)	AD	Architectural Drawings		
3	*Casa della Cultura Cattolica* in Busto Arsizio	SD	Structural Drawings	AP	Architectural Project
4	Church in Viggiù	DR	Design Reports	SP	Structural Project
5	Primary School in *Rione Sempione*, Busto Arsizio	TR	Technical Reports		
6	Primary School in Gorla Minore	MT	Test on building material	Ld	Lacking in details
7	Church of Prospiano	Pcs	Construction-site photos	Lm	Lacking in building material details
8	ITIS School in Castellanza	Pfb	Finished building photos	C	Complete in details

Fig. 11. *Acquired technical knowledge levels, of presented buildings, from the archival sources-based surveys (2019).*

A future applied development of this study may consist of the improvement of digital-model investigation tools [25] for storing and easily sharing archival source data with local institutions charged with the maintenance and appreciation of this local architectural heritage.

6. ACKNOWLEDGEMENTS

This research was conducted within the project "SIXXI: 20th century structural engineering: the Italian contribution" (Erc. Adv. Grant, PI S. Poretti, T. Iori – www.sixxi.eu). The author thanks the architect Stefano Castiglioni for his passionate research assistance in the private archive of the Studio Castiglioni as well as the technical office staff of the Municipality of Busto Arsizio and Gorla Minore.

7. REFERENCES

[1] Iori T, Poretti S (2017) L'ingegneria italiana tra positivismo e umanesimo (Italian structural engineering between positivism and humanism). In: Iori T, Poretti S (eds) SIXXI 4. Storia dell'ingegneria strutturale in Italia (History of structural engineering in Italy). Gangemi, Roma, pp 9–25

[2] Iori T, Poretti S (2016) Storia dell'ingegneria strutturale italiana. Ascesa e declino (History of structural engineering in Italy. Rise and fall). In: Iori T, Poretti S (eds) La Scuola italiana di Ingegneria (Italian School of Engineering). Rassegna di Architettura e Urbanistica 148(1): 8–52

[3] Poretti S (2007) Architettura e struttura in Italia negli anni cinquanta e sessanta (Architecture and structure in Italy in the fifties and sixties). In: Pogacnik M (ed) Adalberto Libera, Sergio Musmeci, Il palazzo della regione Trento. Tra antico decoro e nuove figure strutturali (Adalberto Libera, Sergio Musmeci, *Il palazzo della regione Trento*. Between ancient decoration and new structural figures). Nicolodi, Rovereto, pp 161–184

[4] Desideri P, De Magistris A, Olmo C, Pogacnik M, Sorace S (2013) La concezione strutturale. Ingegneria e architettura in Italia negli anni cinquanta e sessanta (The structural conception. Engineering and architecture in Italy in the fifties and sixties). Umberto Allemandi & C, Torino

[5] Zevi B (1955) Verso un nuovo Linguaggio (Towards a new language). Architettura Cronache e Storia 4: 381–382

[5] Zevi B (1956) Complessi strutturalisti (Structuralist complexes). Architettura Cronache e Storia 10: 240–241

[7] Salvadori M, Heller R (1964) Le strutture in architettura (Structures in Architecture). Etas Kompass, Milano

[8] Musatti R (1955) Concorso nazionale per la stazione di Napoli (National design competition for the train station of Naples). Architettura Cronache e Storia 1: 2

[9] Nizzoli M (1955) Architettura Cronache e Storia 1: cover picture

[10] Ortelli GC (1955) Opere di Enrico Castiglioni (Works of Enrico Castiglioni). Architettura Cronache e Storia 4: 496–511

[11] Kultermann U (1958) Enrico Castiglioni. Bauen + Whonen 10: appendix IX

[12] Anonymous (1964) Enrico Castiglioni. Biggekunst 3: 58–67

[13] Siegel K (1960) Strukturformen der modernen Architektur (Structure and Form in Modern Architecture). Callwey, München

[14] Kultermann U (1965) Neues Bauen in der Welt (New building in the world). Wasmuth, Tübingen

[15] Pevsner N, Fleming J, Honour H (1967) The Penguin Dictionary of Architecture. Penguin books, London

[16] Reid R (1980) The book of Buildings. A panorama of ancient, medieval, renaissance, and modern structures. McNally & Company, London, p 324

[17] Kultermann U (1979) Enrico Castiglioni. In: 28/78 Architettura. Cinquant'anni di Architettura in Italia 1928-1978 (28/78 Architecture. Fifty years of Architecture in Italy). Domus, Milano, pp 94–107

[18] Castiglioni M (1995) Enrico Castiglioni Architetto (Enrico Castiglioni Architect). Dissertation, Politecnico di Milano

[19] Ottolini G, Perogalli C, Langè S, Castiglioni S, Castiglioni M, Magini G (2000) Enrico Castiglioni. I simboli, I significati di un percorso d'arte tra passato e futuro (Enrico Castiglioni, symbols and the meanings of an art journey between past and future). Famiglia Bustocca, Busto Arsizio, pp 10–29

[20] Giannetti I (2019) Architetture costruite di Enrico Castiglioni nella Scuola Italiana di Ingegneria (Built architectures by Enrico Castiglioni in the Italian School of Engineering). In: Garda E, Mele C, Piantanida P (eds) Colloqui.AT.e. 2019. Ingegno e costruzione nell'epoca della complessità. Forma urbana e individualità architettonica, Politecnico di Torino, Turin, 25-28 September 2019, pp 211–220

[21] Anonymous (1964) Escuela elemental en Italia (Primary School in Italy). Informes de la construcción 163: 23–38

[22] Anonymous (1963) E. Castiglioni, Una scuola a Gorla Minore (Enrico Castiglioni, A school in Gorla Minore). Domus 3: 7–16

[23] Anonymous (1963) Premio Nazionale A.I.T.E.C 1962, selezione della giuria, Enrico Castiglioni (National Award A.I.T.E.C. Jury selction, Enrico Castiglioni). Industria Italiana del cemento 1: 26–31

[24] Pedio R (1960) Opere recenti di Enrico Castiglioni (Recent works of Enrico Castiglioni). Architettura Cronache e Storia 60: 366–386.

[25] Capurso G, Giannetti I (2019) 'Reconstructive re-drawings' and 'reconstructive models' for history of construction. The experience of SIXXI research. Tema: Technology, Engineering, Materials 5 (1): 36–46. doi: doi.org/10.17410/tema.v5i1.213

THE USE OF "STRUCTURAL PREFABRICATION" IN THE FLAMINIO STADIUM BY PIER LUIGI AND ANTONIO NERVI. A TECHNICAL-CONSTRUCTIVE STUDY AIMED AT FORMULATING GUIDELINES FOR A FUTURE CONSERVATION PLAN

Rosalia Vittorini, Rinaldo Capomolla

DOI: 10.30682/tema0602b

TEMA Technologies Engineering Materials Architecture

e-ISSN 2421-4574
Vol. 6, No. 2 - (2020)

Highlights

The recovery and conservation of buildings of the 20th century have highlighted the necessity to adopt different methodologies, techniques, and tools from those applied in traditional restoration.
The guidelines, which serve as a basis for future conservation work on the Flaminio Stadium (built in Rome for the XVII Olympics in 1960 and now protected as a cultural asset), stem from a methodology based on a precise reconstruction of the various phases of the project, including its construction, as well as a critical analysis of the original and current physical elements of the Stadium.

Abstract

The paper highlights the specificity and originality of the solutions adopted by Nervi in the construction of the Flaminio Stadium (Pier Luigi and Antonio Nervi, 1957-59), as well as his talent as a designer and engineer. The text presents both a summary of the research carried out on the terracing and the canopy of the Stadium (built using "structural prefabrication") and draws attention to the research methodology, of which this study is a part. The research was funded by the Getty Foundation with the aim of formulating guidelines for the future conservation project of the Stadium.

Keywords

Pier Luigi Nervi, Flaminio Stadium, Structural prefabrication, XX Century, Rome.

Rosalia Vittorini
DII - Dipartimento di Ingegneria dell'Impresa, Università di Roma Tor Vergata, Roma (Italy)

Rinaldo Capomolla*
DICII - Dipartimento di Ingegneria Civile e Ingegneria Informatica, Università di Roma Tor Vergata, Roma (Italy)

** Corresponding author: e-mail: capomolla@ing.uniroma2.it*

1. INTRODUCTION

The recovery and conservation of 20th century buildings have highlighted the necessity to adopt different methodologies, techniques, and tools from those applied in traditional restoration. More precisely, these differences encompass working procedures beginning from cognitive analysis through to intervention.

The methodology followed in traditional restoration is analytical when assessing the state of deterioration and the work to be carried out, deductive when defining the technical choices and methods of intervention, and repetitive when applying consolidated practices. This methodology does not apply to 20th century architecture because each work is unique, especially the technological and construction aspects that are often closely connected to the building's architectural significance. While restoration work has to be considered part of the building's life span and therefore requires a philological-conservative approach, for the works of the 20th century it is necessary to carry out meticulous, accurate and sophisticated cognitive investigations. Furthermore, the restoration must be invisible, even when it involves the development of new construction solutions to resolve existing technical deficiencies.

This methodology was used as the basis for our research for the guidelines “Developing a conservation management plan for the Flaminio Stadium by Pier Luigi and Antonio Nervi in Rome, Italy: an interdisciplinary approach”, which was selected in 2017 by the Getty Foundation in Los Angeles as part of the program ‘Keeping it Modern’. The research − promoted by the Dipartimento di Ingegneria Strutturale e Geotecnica of the Sapienza University (Rome), the Pier Luigi Nervi Project Association, and Do.Co.Mo.Mo. Italy, in agreement with the Municipality of Rome − enabled us to further our knowledge of the Stadium. A fact-finding study focusing on the noteworthy parts of the Stadium, together with an analysis of the historical documentation in the CONI Archive (Rome), the CSAC Centro Studi e Archivio della Comunicazione (Parma) and the MAXXI Centro Archivi di Architettura (Rome), produced the research results which lead to the development of the guidelines for the conservation project.

To illustrate the methodology used in the research, we have provided a brief account of the study of the characteristics and construction of the terraces and the canopy. The results of this study have both a knowledge value which furthers our understanding of a historical event in Italian engineering and a operational spin-off which is not merely descriptive in nature. In this way, when the interpretation of the work is able to grasp the unique characteristics and, above all, can focus on the specific way in which the construction took shape − thus defining the architectural expression − the method of conservation can be adapted to the level of transformation which is compatible with the preservation of architectural values.

Fig. 1. *The Flaminio Stadium.*

2. THE CONSTRUCTION OF TERRACES

The Flaminio Stadium was designed and built by Pier Luigi and Antonio Nervi (1957-59) for the XXVII Olympics in Rome (Fig. 1 and Fig. 2). On April 4 1957, the examining commission for the tender competition (that had been announced by the National Olympic Committee (CONI) in July 1956) awarded the contract to the firm Nervi & Bartoli. Five other companies had participated, with projects submitted by architects specialized in sports buildings design such as: Cesare Ligini and Dagoberto Ortensi, Sergio Bonamico, Enrico Mandolesi, Pio Montesi, Enrico Lenti. Nervi's proposal won because it was functionally efficient, aesthetically acceptable, and was the most economical: only 810,000,000 lire. Work began on July 1 1957 and was completed within 18 months. On the morning of March 18 1959, the Flaminio Stadium was inaugurated by Prime Minister Antonio Segni.

The form and architectural structure of the Flaminio Stadium resulted from Nervi's inspirational invention of a construction system for the stands that was as effective as it was simple. This system of "structural prefabrication" was a process that Nervi used repeatedly, and "consisted of building a resilient complex by linking together prefabricated elements and making them statically binding". As these words suggest the structure, although made up of assembled parts, should not betray the monolithic nature of the organism which for Nervi was "the most characteristic property of reinforced concrete structures […] and was also the one from which its most brilliant and specific static solutions were born" [1]. Nervi realized most of his domes with structural prefabrication: breaking down the surface into small pieces to be built on-site and reassembled to form a single solid structure.

Fig. 2. *The west grandstand.*

The structural prefabrication not only allowed Nervi to realize complex or otherwise unachievable structures, but it also enabled him to reduce construction time and costs by creating finished products that did not require further cladding. In fact, the burden of the formwork was practically eliminated because a substantial part of the structure was constructed from a limited number of molds that could be reused many times.

Structural prefabrication, however, demanded a project construction site that was “more difficult and delicate […] with very few established points of a general or theoretical nature”. It “must fundamentally be based on experience, on similarities, and above all on a *practical imagination* that includes all the phases of processing, transport, and assembly so that each can be defined with sufficient accuracy” [2].

In the case of the Stadium, structural prefabrication also served to rationalize the site and solve problems that would not have otherwise been possible using traditional methods. The construction planning – which Nervi had tested and used in other projects – was essentially a series of 92 reinforced concrete supporting frames, cast on site, with a “covering” (in this case the cavea of the Stadium) made of prefabricated elements, from which the terraces and the canopy were made.

When preparing the competition project, Nervi came up with a basic-element from which the entire *cavea* could be constructed: a hollow step with a rectangular trapezoid section. Each face of the step had a specific function: the vertical faces were the supporting beams; the horizontal face, the seating; the slanting face, the component which collected rainwater. Nervi patented this system even before completing the competition project [3] (Fig. 3).

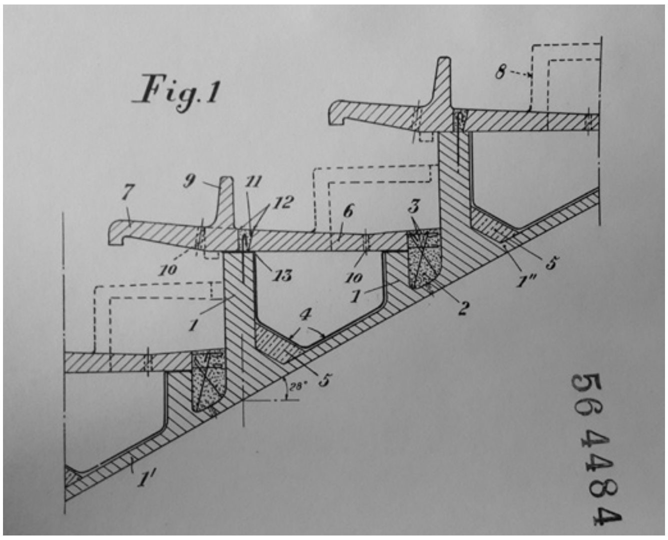


Fig. 3. *P.L. Nervi, Patent n. 564484, January 12 1957.*

Nervi identified three principal problems concerning the construction of the terraces. The first was the waterproofing. If the grandstands were made of load-bearing reinforced concrete steps, “it becomes very difficult to cover the water-repellent layer above with cement-based plasters, because it would be impossible to make them adhere effectively […] to the supporting structure”. The problems persisted even when the steps were built on an inclined slab because the waterproofing layer covering the slab “could lead to slippages of the steps on the underlying support structure”. Then there was the problem of the rainwater, which could not be allowed to run down the terraces. The final concern was the visibility of the playing field: to make it optimal, it was necessary to increase the slope of the steps gradually. This could be achieved by maintaining a constant lift and increasing the tread as it approached the playing field, but this would have reduced the capacity. Alternatively, it could be realized by keeping the tread constant and progressively increasing the lift as it moved away from the playing field, but this would have increased the height of the seat, which, “for the comfort of the spectator”, should remain constant.

To resolve these problems, Nervi’s patent proposed a step made of two prefabricated components. One had a U section which rested on the supporting frames of the stands, and “had a static function of collecting and conveying water”. The other, covered and supported by the first, “constituted the tread and the seat”. The U-shaped elements – once bonded both reciprocally and with the supporting frames (through small concrete casting that incorporated the protruding bars) – were waterproofed to the extrados before mounting the tread seat. In this way, the first problem was solved, and the rainwater runoff down the terraces was also avoided (as the water that collected on the tread was removed through a hole that delivered it to the U-shaped element). From there, it was conveyed to a second hole that disposed of it in a sheet metal tube, visible at the intrados of the terraces. Finally, Nervi achieved a constant seat height by simply using a seat protruding from the step. In this way, it uncoupled its height from the position of the tread.

Nervi knew that for the solution to be economically viable it had to be restricted to a limited number of typical-elements which could be repeated many times and the enveloping shape of a Stadium *cavea* did not guarantee that the selection of the pieces would be limited. It is, therefore, reasonable to think that Nervi initially focused on the geometry of the stands in order to make it as compatible as possible with the steps of his invention. In fact, the cavea, symmetrical with respect to the east-west axis, had an elementary geometry: four planes, inclined towards the sides of the playing field, and four cone-shaped connecting surfaces, at the corners. There was, however, an unavoidable geometric complication. The terrace planes had different extensions; hence their upper sides were at different heights, which meant the cone quarters did not align with the circular arc. Nervi, therefore, chose an easily traceable crooked line: which was the intersecting line of the conical and cylindrical areas that had a vertical axis not coinciding with the cone axis. The result was a toping line that appeared to be continuous, flowing, and harmonious. From the outside, it made the Stadium look “less bulky”, and from the inside, it removed “the viewer from the feeling of being in a closed environment” [4] (Fig. 4).

Despite the simplification of the geometry of the whole, the typical-elements of the steps were numerous. There were straight pieces used for the seating area of the east and west grandstands, the standing area and the parterre of the north and south grandstands, and the seating area of the west parterre (Fig. 5).

In addition, there were the curved pieces of the corner terraces, which had different lengths and curvatures. Above all, there were many special pieces, both curved and straight, such as those near the upper edge of the conical areas intersecting the crooked top beam, which were triangular or trapezoidal; those in the vicinity of the *vomitoria*, to the ascending and descending stairs, to the expansion joints, to the curved perimeter of the north and south parterres, and the areas reserved for the journalists and authorities. In addition, almost all the types were tripled because the inclination of the terraces (both flat and conical) was not constant but passed from 28 to 30 to 32° to allow for perfect visibility of the playing field.

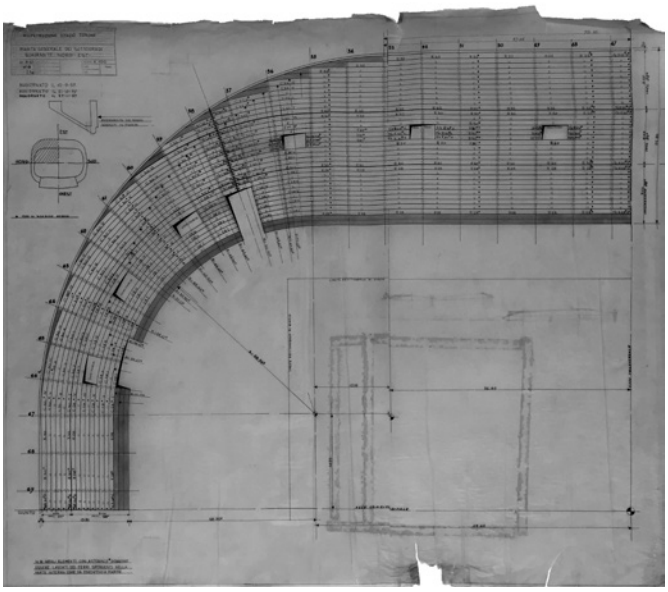


Fig. 4. *Northeast quadrant of the Stadium.*

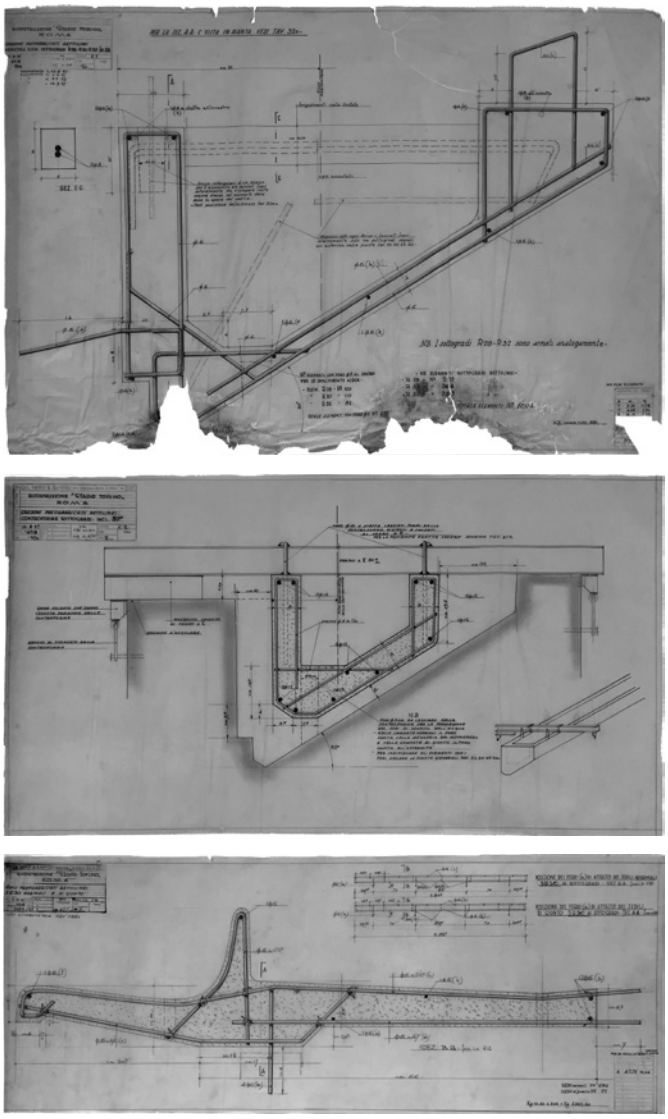


Fig. 5. *The prefabricated steps: U-shaped reinforcement element; fixed and counter-mold for U-shaped element; straight seat element.*

Aware of how delicate and difficult the process was, Nervi, even before working on the planning and structural design of the supporting structures (foundations and frames), was keen to plan and start the prefabrication site of the steps immediately.

When making the risers (finished on both sides), he used a fixed mold (the "*forma a terra*") to shape the intrados, and a removable concrete counter-mold to shape the extrados (Fig. 5). On the construction site, molds and counter-molds of different shapes and sizes were available: their number was calculated in relation to the elements to be made for each type. There was an identical assortment regarding the tread elements, which were both seats with a small backrest (Fig. 5) and stepped components for the standing room.

To give an idea of the variety, it suffices to say that the rectilinear risers, the simplest ones, not only belonged to three different families according to the inclination of the stands, but they also had to be supplied in different lengths − 536 centimeters or 2/3, 1/2, 1/3, 1/6 of this measure − depending on whether they were the base-pieces or the special pieces in proximity to the *vomitoria*, the ascending and descending steps, the expansion joints. There were also secondary variants for each type which dealt with the water-draining outlets, the closure or otherwise of the heads of the risers, and the different reinforcement and positioning of the protruding bars. Finally, further differences were envisaged when the elements, instead of being supported, were cantilevered, such as those on the sides of the vomitoria and the expansion joints − because in this way the tubes became disposable formworks for suture castings, with which real reinforced concrete beams were made. Despite these complications, the prefabrication site managed to produce an average of 35 elements a day, for a total of 7652 pieces (Fig. 6).

Fig. 6. *The construction site: on the ground the prefabricated elements of the steps.*

3. THE CANOPY

The prefabrication of the canopy elements presented fewer problems as there were only 88 pieces, and the typical-elements were only two: rectangular, 14.30 meters long, 1.425 meters wide (4 per span) and 1.2 meters high at the joint; and a piece of the same length, but with a plan in the form of a sector of an annulus, to cover the curved end parts of the west grandstand. Once assembled, their V-section produced an elegant pleated surface perforated with numerous, small circular apertures. The two faces of each component, delimited above and below by ribs, were not flat surfaces but hyperbolic paraboloid ones. Two transverse stiffening joists joined the upper ribs, preventing deformation of the components (Fig. 7).

The canopy as a whole was made up of two parts: the portion formed by the prefabricated components and a rear concrete platform resting on the extensions of the corbels of the supporting frames, and in front, on twenty-two slender struts of steel tube filled with concrete.
In the competition project, the canopy was resting on tubular steel uprights, but the covering elements had a tube section, very similar to those of the canopy of the semi-circular pavilion of the Fiera di Milano (1952). The tubes, envisaged in *ferrocemento*, were five per span and 14.6 meters long closed at the top by thin hollow brick and concrete casting. The whole had a height varying from 45 (at the free end) and 110 centimeters (at the embedded end). The wavefront was hidden by a tall front-band. The rear platform, cast on-site, was made up of a 5 centimeters slab and a ribbed extrados: in this way, a closed box section with a height varying between 90 and 110 centimeters was realized.

The shape of the canopy in the final design remained substantially unchanged, but the shapes of the prefabricated components became V-shaped and were made in that form.

The procedure for the construction of the canopy components was different from that of the terraces; they were, in fact, of *ferrocemento*. A steel grid of small-diameter bars was used to support three to four layers of thin steel mesh, on which the cement mortar was smoothed with a trowel, creating layers only 3 centimeters thick and ribs of 10-15 centimeters on the side.

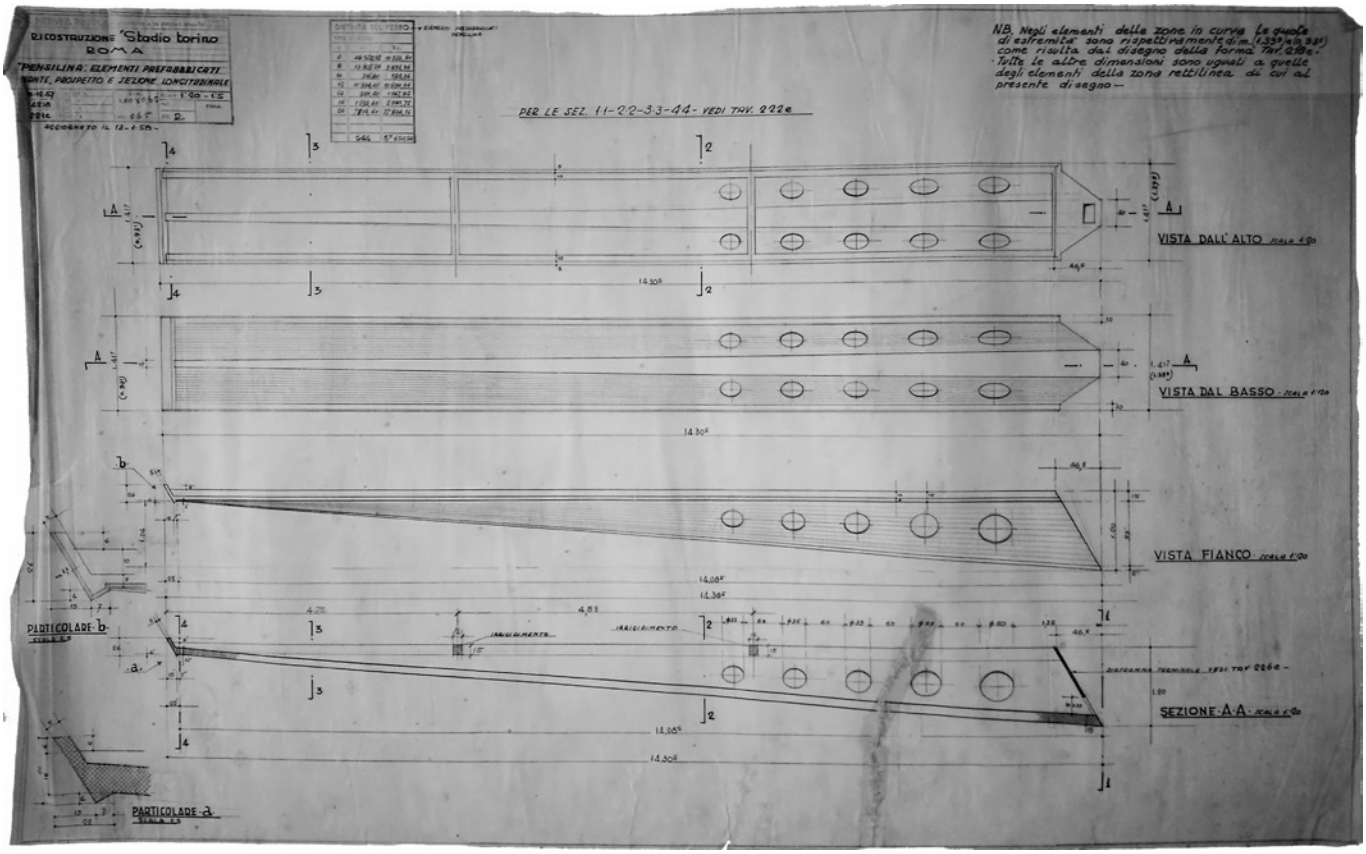


Fig. 7. Ferrocemento *element.*

In May 1958, Nervi developed an apparently slightly different solution in which the static structure of the roof was more clearly expressed. It entrusted the traction induced by the inclined strut to a reinforced concrete tie-beam, separated from the roof, which behaved like a simple resting structure (Fig. 8). It was a brilliant solution that was reproduced in the Swindon Stadium project (1963-66).

4. "COSTRUIRE CORRETTAMENTE"

The site set up by Nervi for the construction of the load-bearing structures used a hybrid construction process that saw the coexistence of structural components made on site of prefabricated elements, and of finishing parts (made in situ) for the margin of the *cavea* (crowning of the stand, lower ring, border of the *vomitoria*). The immediate goals, unavoidable for a construction company such as Nervi & Bartoli, were certainly those of reducing construction cost and time. However, in the case of Nervi, these aims were not separated from the need to obtain a convincing formal result. Indeed, for Nervi, the correctness of the formal outcome was somehow guaranteed by the effectiveness of the construction process itself. This was also the case of the Stadium, where there was an inseparable bond between technical invention, construction method, and the formal result.

Fig. 8. *The west grandstand.*

The pre-eminence that Nervi gave to the structural fabric over the rest of the construction is demonstrated by the fact that no element of the supporting structure was kept hidden, even in circumstances when revealing its presence did not seem significant. Furthermore, Nervi proposed to sandblast the concrete of the frames to enhance the surface texture, a treatment he had recently used for the UNESCO site in Paris (designed by Marcel Breuer and Bernard Zehrfuss). Nervi advised CONI: "the purpose of blasting was not to clean the surfaces of the reinforced concrete […] but to highlight the formwork design by removing the grout veil on the treated surfaces that made them uniform. In fact, all the exposed reinforced concrete works carried out before sandblasting was adopted, having remained rough as after disarming and without any treatment, have clean but less lively surfaces than those sandblasted at the Flaminio Stadium" [5].

The areas under the stands (dressing rooms, swimming pool, and gyms) followed the geometry of the cavea, developing in a continuous ring that occupied a strip of the covered area. Purposely, therefore, the geometry of the spaces did not come into conflict with the geometry of the structure. Even the walls were subtle, almost neutral, spreading out in single surfaces, which unequivocally showed their secondary role as infill for the spaces between the frames. The same can be said of the windows that, in the form of large windows or strips, always developed from one frame to another (Fig. 9). This planning can also be seen in the details (always very simple, apart from some elements such as the steel staircase of the swimming pool) and fell within the established construction tradition of those years, which drew on repetitive solutions with a limited number of variants.

The Flaminio Stadium is an example of the "*costruire correttamente*" pursued by Nervi, that identified a static-construction system, which then became the heart of the project. This way of working led to an "essential" architecture which is apparent in most of Nervi's work, and bases its value on the economy of forms and, when necessary, the materials that show with truthfulness and sincerity the way it was built, which is the case of the Stadium.

Ultimately, one could describe the Flaminio Stadium in the terms Nervi used to describe the requirements that an architectural work must possess: “it must be a stable, unified, resistant organism, in accordance with its environment and with the functions that it must perform, balanced in all its parts, clear in its support structures and its technical elements, and at the same time capable of giving that indefinable emotion that we call ‘beauty’” [6].

5. CONCLUSIONS

The structural prefabrication site that Nervi set up for the Flaminio Stadium was not dissimilar to those used in other projects. Only an experienced and well-tested firm like Nervi & Bartoli could have undertaken such an enterprise that was not – at least for the variety of prefabricated pieces to be prepared – comparable to others. It was essential that the firm, in order not to risk increasing the cost and lengthening the construction time (already limited), carefully planned out the form and specific components of the

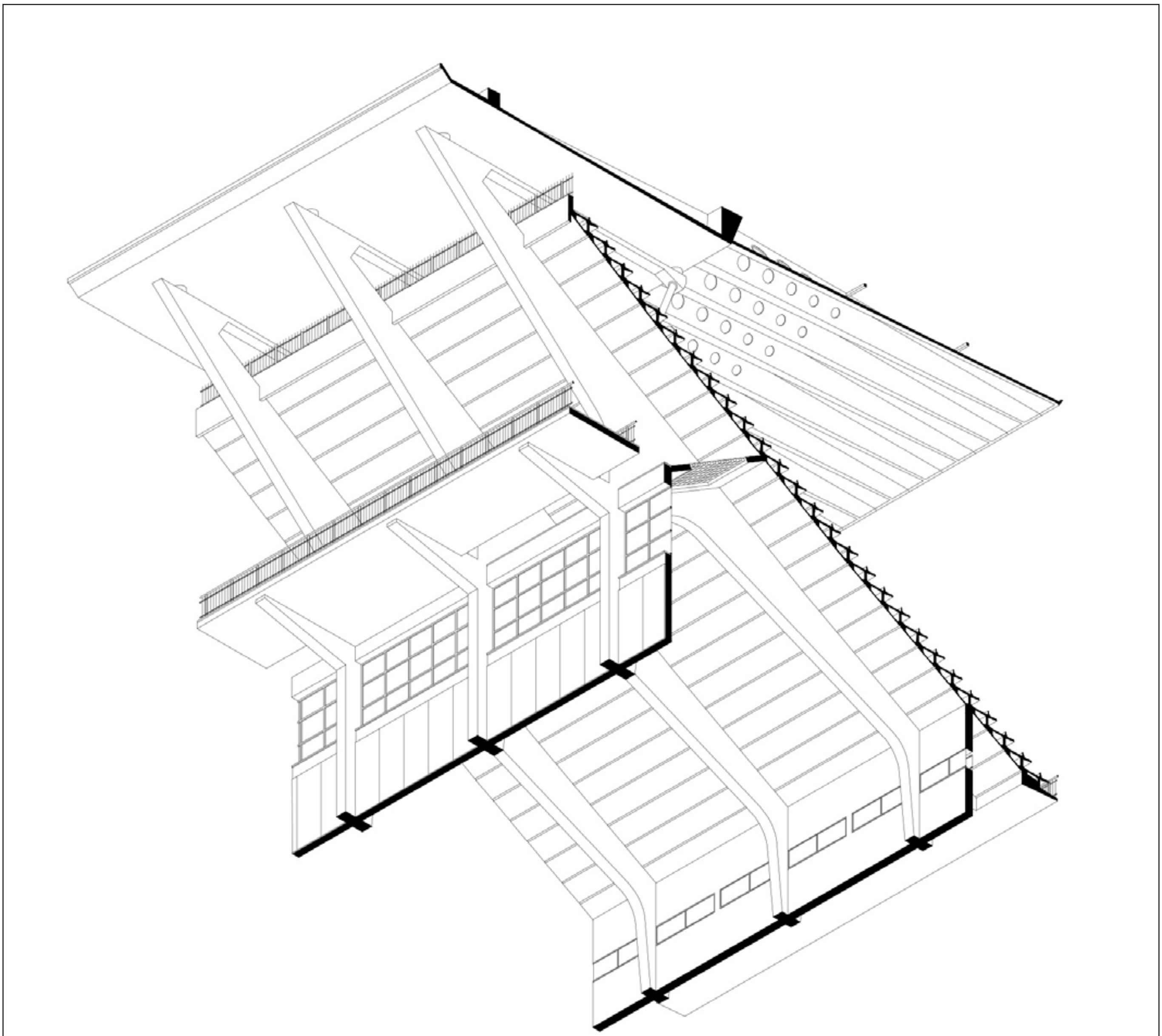


Fig. 9. *Guidelines: axonometric view of west grandstand (authors’ drawing).*

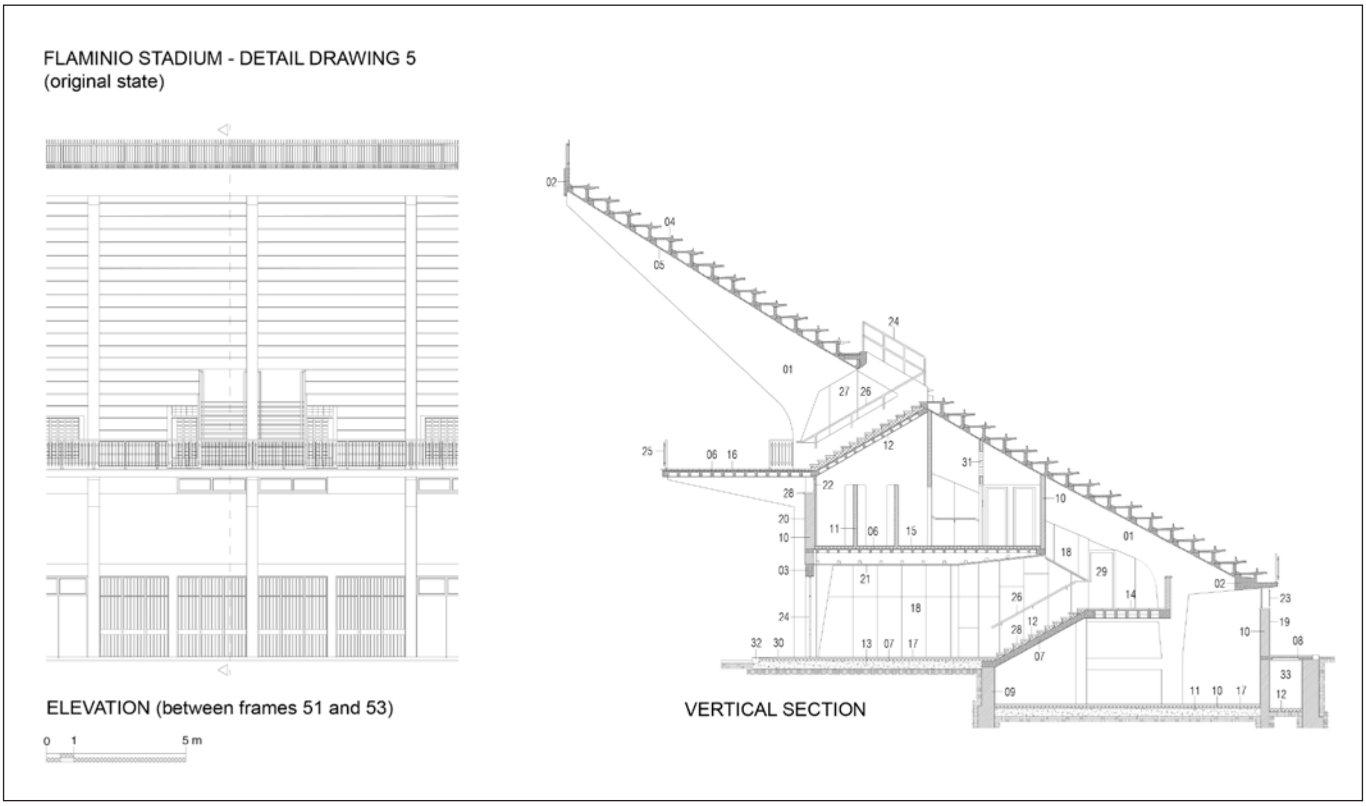


Fig. 10. *Guidelines: detail of the original state between frames 51 and 53 (authors' drawing, with D. Chiarello and T. Valentini): 01. Exposed concrete frame - 02. Exposed concrete edge beam - 03. Exposed concrete beam - 04. Precast concrete seat - 05. Precast concrete riser - 06. Hollow brick and concrete floor - 07. Concrete floor - 08. Low hollow brick and concrete floor - 09. Tuff stone wall - 10. Brick wall - 11. Perforated brick wall - 12. Concrete layer - 13. Drainage layer - 14. Travertine slab floor - 15. Gres tiles floor - 16. Concrete tile floor - 17. Rubber floor - 18. Rough travertine slab cladding - 19. Small travertine plank cladding - 20. Plaster - 21. Suspended ceiling - 22. Window with 'ferrofinestra' frame - 23. Steel mesh grate - 24. Steel gate - 25. Steel railing - 26. Steel handrail - 27. Safety glass plate - 28. Travertine slab - 29. Plywood door - 30. Asphalt layer - 31. Perforated brick screen - 32. Travertine edge - 33. Interspace.*

building to be used together with a thorough study of both the manufacturing methods and the assembly of the parts. Only Pier Luigi Nervi could have taken on and managed such a demanding undertaking.

Today the Stadium is abandoned, and its future is uncertain. The reconstruction of the phases of the project, which include: the construction site, the analysis of the original physical structure of the Stadium (for example, those relating to the terraces and the canopy), and the analysis of the subsequent additions are indispensable steps in formulating the conservation plan. This is the objective of the research project within which our study is placed.

In the guidelines, the analysis and project planning documents relating to the individual building parts are flanked by drawings of the "parts", necessary to clearly describe the architectural and construction specifics of the Stadium (Fig. 12). These two documents are both a concise tool for making the defining elements of the Stadium better known and an operational tool for the implementation of the conservation project.

In particular, the study recognizes the grandstands as a unitary body which despite their present "fragility" must be preserved, not only in appearance but also in their original form, as an authentic testimony of the specifically devised and unique construction system. Consequently, the guidelines for the supporting structures provide not only for the restoration of the Stadium's original features, eliminating the additions and all the subsequent cladding, but also for the philological restoration of the prefabricated elements (still largely present), and the integration of those that are missing or severely deteriorated. This "fundamentalist" position did not, however, prevent us from recommending a preliminary solution for one of the most severe construction problems − that of the rainwater collection and disposal − which allowed for effective, reversible, supplementary or replacement technical solutions (if more effective) than those identified by Nervi.

6. REFERENCES

[1] Nervi PL (1945) Scienza o arte del costruire? Caratteristiche e possibilità del cemento armato. Edizioni della Bussola, Roma. New edition (2014) ed. by Neri G. CittàStudi Edizioni, Milano, pp 77–78

[2] Nervi PL (1965[2]) La prefabbricazione strutturale. In: Id. Costruire correttamente. Caratteristiche e possibilità delle strutture cementizie armate. Hoepli, Milano, pp 33–36

[3] Patent n. 564484 "Sistema di costruzione di gradinate di cemento armato ad elementi pre-fabbricati per stadi o tribune per spettacoli, e relativi elementi pre-fabbricati" by engineer Pier Luigi Nervi, January 12 1957. Central State Archive, Roma

[4] Nervi PL "Ricostruzione dello Stadio Torino, Roma. Relazione architettonica". Report, January 31 1957. CONI Archive, Roma

[5] Ibidem

[6] Huxtable AL (1960) Pier Luigi Nervi. Il Saggiatore, Milano, p 21

ITALIAN BUILDING MODELS IN THE 1950s. THE AGIP MOTELS

TEMA
Technologies Engineering Materials Architecture
e-ISSN 2421-4574
Vol. 6, No. 2 - (2020)

Giorgia Predari, Riccardo Gulli

DOI: 10.30682/tema0602c

Highlights

An important chapter of Italian construction in the 1950s was the assets of the Agip Company, later ENI, which began to build a dense network of petrol stations along the main Italian roads, accompanied by motels intended for the rest of travelers. Among these, there were many unique works never replicated, but there was instead a recurring type, called Model 59, which was re-proposed in at least 35 Italian sites. From the study of this type of building, we can understand how reinforced concrete buildings were built in the 50s, then formulating hypotheses on how we can intervene today to improve its behavior from a structural point of view.

Abstract

The paper deals with the performance characteristics of the Model 59 of the Agip motels, which is highly representative of the Italian construction during the economic boom of the 1950s and 1970s. A large-scale study has pointed out the position and the current state of all the fifty Agip motels designed and built between 1954 and 1970, thanks to a precise archival and digital research. Among these, the most common was the Model 59, whose project was drawn up by the engineers of SNAM Progetti and built in at least 35 Italian sites, with slight differences from a standardized construction type.

Keywords

Agip motel, Model 59, ENI, SNAM Progetti, Enrico Mattei.

Giorgia Predari*
DA - Dipartimento di Architettura, Alma Mater Studiorum - Università di Bologna, Bologna (Italy)

Riccardo Gulli
DA - Dipartimento di Architettura, Alma Mater Studiorum - Università di Bologna, Bologna (Italy)

** Corresponding author:*
e-mail: giorgia.predari@unibo.it

1. INTRODUCTION

The second post-war period is rightly defined by historians as a new "golden age", as these were years of "extraordinary economic growth and social transformation, which probably modified human society more deeply than any other period of similar duration" [1].

This quote is particularly appropriate for the Italian context, where there was a period of rapid economic growth between the 1950s and 1960s, which substantially changed the Italian panorama; Italy was transformed from a country with a predominantly agricultural economy into one of the main industrial powers in the western world.

After the Second World War, the Italian demographic trend experienced a long period of growth, at least until the beginning of the seventies, when a stabilization occurred. From an economic and productive point of view, for the first time, in 1958, the number of employees in industry exceeded the number of employees in agriculture, following a process that allowed Italy to become a predominantly industrial country. With the reduction of agricultural activities, the production system and social relations based on the predominance of the human workforce were gradually abandoned, assisting the spread of machines and industry.

Industrial production was driven by the metalworking industry and the petrochemical sector; within this framework, in 1953 the *Ente Nazionale Idrocarburi* (ENI) was established with the presidency of Enrico Mattei, a key figure in post-war Italian history, whose actions left tangible signs for the development and economic recovery of the country [2, 3].

In 1945, Mattei was commissioned to liquidate AGIP (*Azienda Generale Italiana Petroli*), the Italian public oil company founded in 1926. However, Mattei opposed this liquidation and, instead of closing the company, he relaunched it; he opened new petrol stations and inaugurated a network of motels with the first petrol stations. Later, he promoted a drilling campaign in the Po Valley, which led to the discovery of methane deposits. Within a few years, these made ENI a holding company at the head of a varied industrial empire, with ramifications also in the production of synthetic rubber, fertilizers, and gas tanks.

2. THE NETWORK OF AGIP MOTELS

The construction of the so-called *Sun Motorway* (Autostrada del Sole) began in 1956 and it was completed in 1964 [4]; in these years, Enrico Mattei decided to start the ambitious project of a complex network to support this infrastructure and, in the 1950s, he started the construction of a series of service stations, which had to be attractive for travelers.

The design of these service buildings was based on the uniformity of the adopted techniques to make them recognizable throughout the territory thanks to the proposal of solutions that preserved the same characteristics everywhere, from the external appearance to the interior furnishings. The areas had to be always arranged with the same sequence and the rooms had to be organized with the same internal structure, in order to arouse a sense of hospitality and familiarity in travelers. The location covered almost the entire national territory, along the state, provincial roads, and highways of small and large cities [5, 6].

The petrol stations included mechanical workshops, a washing area, large squares, and spaces for parking trucks; often there were also rest stops with bars, restaurants, and hotel facilities. These were called Motel Agip.

The building typology of the *motel* (abbreviation for Motor Hotel) was born in America, where traveling distances were so long to make regular stops necessary. In the United States, famous architects gave their contribution in this sector, but a real architectural language has never developed with precise and recurring characteristics. Mattei had made several trips to the United States and he knew this situation; therefore, he decided to import it in Italy, but adding his personal intuition, making recognizable the motels in his chain, thanks to their replication with the same characteristics throughout the national territory.

So, starting from 1954, the Agip Company started an intense program for the construction of motels on owned lands along the main roads throughout Italy [7]; the purchase of these areas was assessed on the basis of careful studies, which analyzed the car flows, the distances from highways and the amount of long-distance traffic related to that location.

The motels were located along the main roads of the national territory, in the capital cities and sometimes even along the highway itself, as is the case of the Agip motel in Modena, which was accessible both from the highway and from the city.

By the end of 1962, Agip already had more than thirty motels; despite the death of the inventor, Enrico Mattei, the project was later carried out by his successors, so that today we can count fifty hotels throughout Italy, that were born as Motel Agip. Six Agip Motels were also built abroad; in the late 1950s, following the choice of ENI to internationalize, a motel was built in Kenya, one in Tanzania, one in Madagascar, three in Ethiopia and in the Ivory Coast.

ENI maintained the petrol stations management, as well as the Agip Motels and the meal services, until the 1990s, when the company was forced to divest all facilities.

Nowadays, in some cases, the motels have been sold to private individuals while maintaining the same hotel function, or have changed use, or have been abandoned.

3. SOME UNIQUE PROJECTS

The design of the first Motel Agip in Italy was entrusted to the architect Mario Bacciocchi, who conceived the Motel Agip in Metanopoli in 1954. The motel was preceded by a courtyard, which was bordered by a narrow colonnade on one side and a stone-clad building on the other. The building had a three-story reinforced concrete frame structure and it was coated in wood and covered by a pitched roof, a recurring element in Baciocchi's architecture.

Between 1954 and 1956, Edoardo Gellner's motel was built in Cortina, who was in charge of drafting the city Master Plan for the 1956 Olympic Winter Games [8]. After an initial project drawn up by Mario Baciocchi, which was not approved due to the lack of adaptation to the landscape and to the local style, the assignment was entrusted to Gellner, who was also the designer of the ENI tourist village near Cortina. The designer adopted an individual and contemporary language; the building was supported by a reinforced concrete load-bearing structure with external walls covered with wooden planks, and the ground floor was set back so as to leave the structure visible.

In the following years, Mario Baciocchi [9] designed the motels of Bolzano and Voghera, dating back to 1962, which respected the architectural references of the area instead of those designed as a distinctive image of ENI.

Most of the subsequent projects were instead managed by the engineers of SNAM Progetti [10], the leading engineering company in the sector of design and construction of large onshore plants (such as refineries, pipelines,

Fig. 1. *The Agip Motels of Metanopoli, Bolzano, Cortina, Modena and Pisticci.*

and environmental activities in the hydrocarbons field) belonging to the ENI group. Between 1950 and 1965, SNAM Progetti was responsible for the design of the Agip service stations, the Ristoragip and the Agip Motels.

There were, however, some exceptions; singular cases were commissioned to the trusted architects of Enrico Mattei, Ugo Ratti and Marco Bacigalupo, who designed original and atypical solutions, still functional and well recognizable today (Fig. 1).

In fact, in the early 1960s, the architects Ratti and Bacigalupo designed the Agip Motel in San Donato Milanese [11, 12] with a 14-story reinforced concrete frame structure, which still functions as a hotel, and the similar Agip Motel in North Florence, in Sesto Fiorentino. In Matera, instead, there was the Motel Agip of Pisticci, an interesting construction carried out in 1964 and now abandoned. It is one of the most elegant solutions that the Bacigalupo and Ratti studio has ever designed for ENI; it is a two-story building, with a reinforced concrete frame of three levels and with a large planimetric extension, which rests on pilotis and uses the space below as a parking lot. The distribution system is located outside the building so the rooms are not accessed from inside the building, but from the outside, through a path hidden by a system of slats that regulate the entrance of the sun rays.

More recent are the projects dating back to the early 1970s for the Agip Motel in Modena, with a height of nine floors, which today was decommissioned after a fire; similar buildings were in Pescara, with an extension of five floors and still functional, and in Vicenza, which was demolished in 2008.

A further singular case was entrusted to the architect Enrico Fattinnanzi, who designed the Motel Agip in Duino Aurisina in 1967, with such a conformation to make it unique, located in a green area and mainly horizontally extended.

4. THE DESIGN SCHEME OF THE "MODEL 59"

At the end of the 1950s, Enrico Mattei, with the support of SNAM Progetti's engineers, decided to design a "typical" model for his motels to be re-proposed throughout Italy with the same characteristics; it was called "Model 59".

The main purpose was to create a simple and effective architecture that would become the symbol of Agip and that would be recognizable, where the traveler could find a familiar and welcoming resting place, regardless of the city where he was.

The configuration of the "Model 59" consisted of a rectangular plan, with a variable number of spans according to the flow of travelers that were expected, and consequently the need for accommodation.

It was rigidly organized on a basement floor that housed thermal plants and machinery; the ground floor included the common services, such as the restaurant, the reception room, and the conference rooms; the upper floors were dedicated to the bedrooms and the attic floor housed the motel manager's apartment.

From an architectural point of view, the "Model 59" was formally very simple and made with low-cost materials, in order to devote more attention to internal details (Fig. 2).

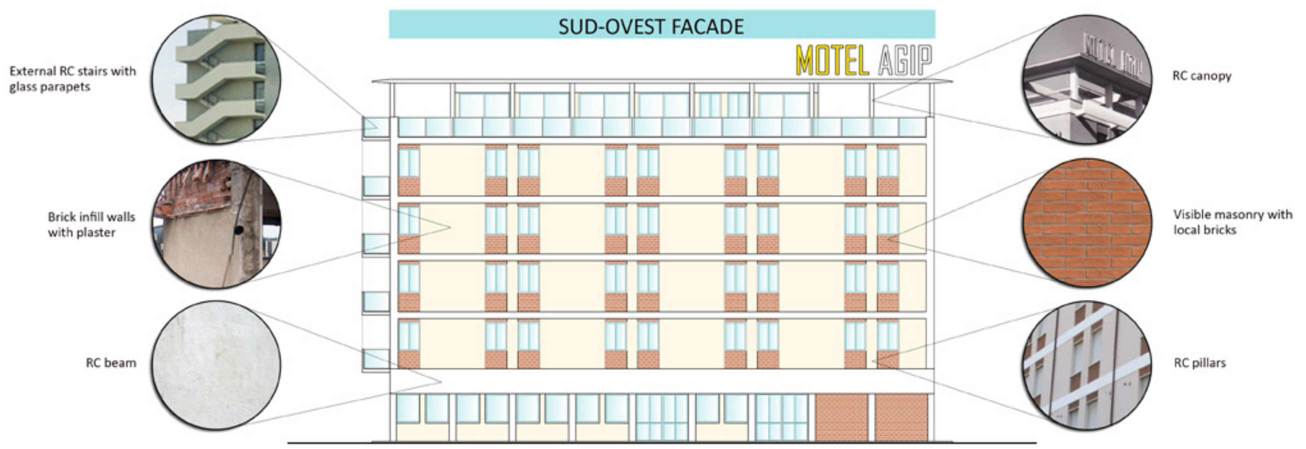


Fig. 2. *Façade organization of the Model 59 (graphic elaboration by Greta Casi).*

Fig. 3. *Distribution of Agip motels in Italy; in blue, Model 59. It should be noted that in Sicily and Sardinia, the present Agip motels were all from Model 59.*

It adopted a reinforced concrete frame structure, articulated on three, four or five levels, with pillars at a regular distance of 3.30 m, brick infill and a base with a stone cladding for the ground floor.

All the "Model 59" had in common a particular construction placed at the top of the building, a sort of canopy with a flat roof that followed the external perimeter and where the large "Motel Agip" sign was positioned.

The accurate archival investigation, conducted through the exploration of the ENI Historical Archive of Pomezia, in addition to an extensive digital research, has allowed to find out the location of all the Agip Motels on the national territory and to recognize the thirty-five still existing "Model 59". Some of them are still functional, others have been abandoned and others have undergone radical transformations (Fig. 3).

5. THE "MOTEL 59" IN BOLOGNA

The characteristics of the "Model 59" in Bologna find a perfect match with the motels of the same model built in other Italian cities, confirming Mattei's desire to create a type to be proposed repeatedly throughout Italy with small variations, linked to the localization area and the flow of cars.

The Agip Motel in Bologna was built in 1959 in the Borgo Panigale area, along the SS9, now called Via Emilia Ponente, the road connecting Bologna to Modena. It represents a standard case of "Model 59", without substantial variations if compared to the basic type. The lot, carefully chosen and purchased by Mattei himself, was located in a strategic position, as it is not far from the motorway junction and always traversed by vehicular traffic.

The first documents of the project date back to 1959 and represent the motel with the adjacent service station, built a few years earlier. One of the characteristics of "Model 59" was the constant presence of the service station facing the road next to the motel, to allow travelers to refuel and to stay overnight.

The building had a rectangular shape, simple and effective for a rational internal distribution, with a planimetric footprint of about 15x30 m. It stood on seven strictly organized levels: the basement housed areas that were accessible only to personnel, such as engine rooms, warehouses, thermal plants, laundry, and toilets for employees. The ground floor was divided into spaces for common use, such as the restaurant, the entrance hall, the waiting room, and the customer toilets; the first, second, third and fourth floors housed exclusively the bedrooms and, finally, the attic floor was intended for the director's residence, plus any service rooms for the employees (Fig. 4).

Externally, the Agip Motel in Bologna replicated the image of the similar models, with the reinforced concrete frame left visible, brick infill walls painted in a neutral color, two-door windows that underline the vertical scan of the facades. Only the attic floor had larger windows. Like every "Model 59", in addition, the attic was surrounded by a reinforced concrete canopy that supported the large white and yellow "Motel Agip" sign. The external stairs were also in reinforced concrete and completed by a glass parapet.

As already mentioned, the load-bearing structure consisted of a reinforced concrete frame, with pillars

Fig. 4. *The "Model 59" in Bologna. Images of the exterior and interior spaces in the 1960s.*

at a 3.30 m distance and with dimensions varying from 45x40 cm maximum in the basement to 30x30 cm minimum in the attic floor.

The foundations were made with type 500 cement and smooth type Aq 42 rods, while for the elevation structures, type 680 cement and TOR bars were used. The floors were of the so-called "Excelsior" type, a particular hollow-brick floor produced since the 1930s by the Rizzi, Donelli and Breviglieri Company [13–15]. This type of floor was cast in place and had only parallel ribs, with the compression slab made of brick and not of reinforced concrete; it was generated by the hollow-brick upper conformation.

The "Excelsior" type of floor was widely used around the mid-1950s because it was useful for many reasons: it had a high rigidity, due to the collaboration between concrete and brick; it was quick and simple to build; it was efficient, since at the extremes where the bending moment was negative, it was possible to overturn the hollow blocks by placing the slab downwards so as to absorb the compression efforts, without therefore adding special elements; it was relatively light, thus allowing a decrease in the floors' own load. It was produced with a thickness of 12, 15, 18, 22 cm and the ribs had a width equal to 6 or 8 cm, with a weight between 110 and 200 kg/m^2.

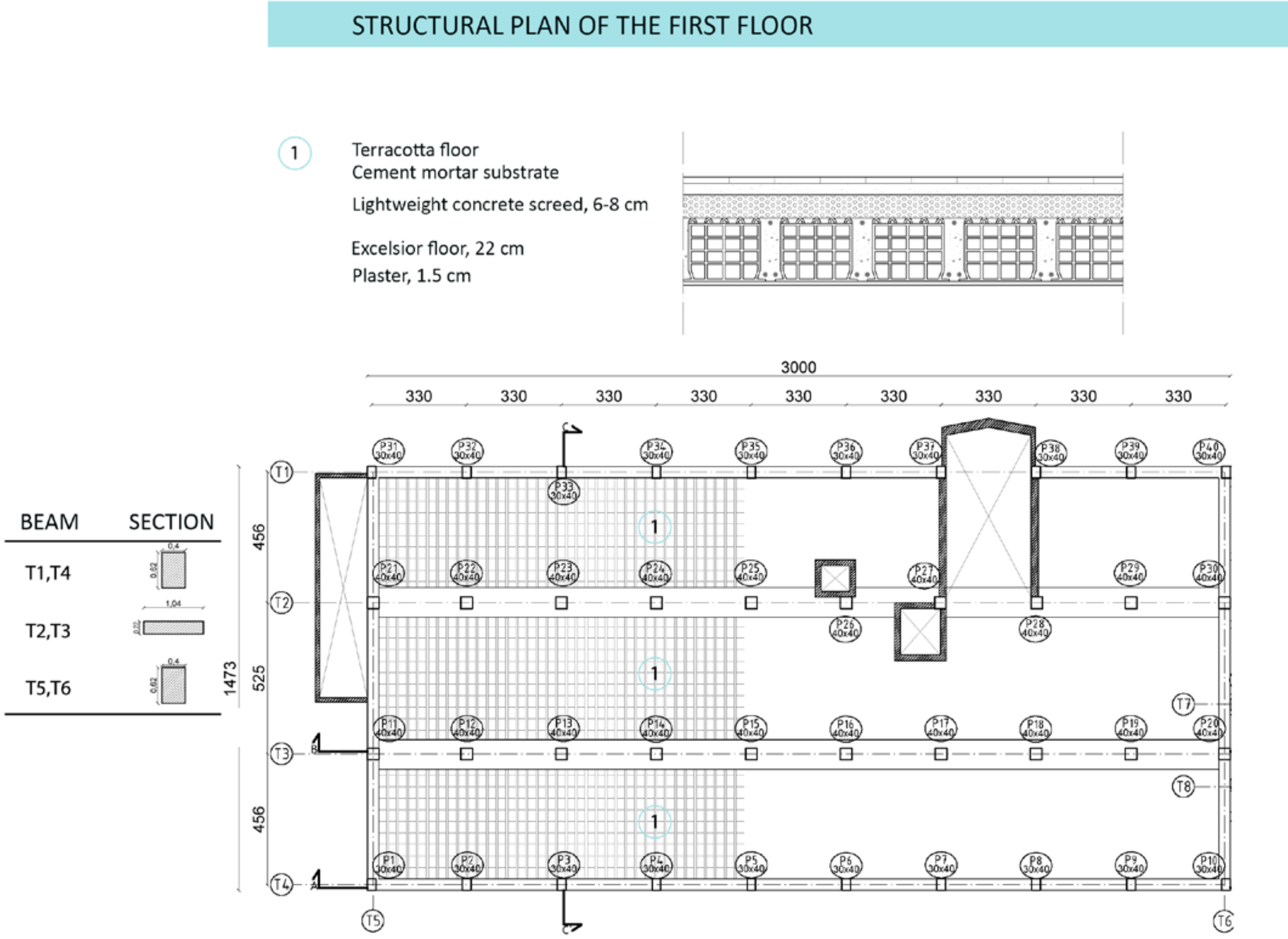


Fig. 5. *Structural plan of the first floor (graphic elaboration by Greta Casi).*

For the Agip motel in Bologna, "Excelsior" floors with two different thicknesses were used: 22 cm for the ground floor, the first floor and the attic floor; 18 cm for the intermediate floors and the flat roof (Fig. 5).

The nearby petrol station was also a model to be similarly proposed on all highways and state roads; it was also called 59, as it accompanied Motel 59. It had a single floor, hosting the workshop and car washing area, too. The external finishes were very simple, with exposed brick infill walls and a slightly protruding reinforced concrete roof.

In 1989, an expansion intervention was implemented on the Agip Motel of Bologna, with the construction of a new block having similar size and adjacent to the existing one, also carrying out an overall transformation of the facades. In 1992, together with other seventeen motels, the building was then sold to a private company, which maintained the hotel function.

6. THE STRUCTURAL BEHAVIOR OF THE "MODEL 59"

Once the construction characteristics of the building were analyzed, the current performance in terms of earthquake response was estimated through the use of finite element modeling software.

First of all, the critical aspects of the structure were identified [16]; these are the recurring vulnerabilities that we can detect in existing buildings that have been designed without regulatory requirements in terms of earthquake resistance, with lower quality materials than the current ones and with reduced mechanical characteristics for the application of the necessary reduction coefficients due to the lack of specialist investigations.

The analysis has therefore shown that, at present, 30% of the vertical elements are verified for shear and buckling, and only 11% of the beams are verified for shear and bending moments (Fig. 6).

With the aim of maximum compatibility and minimum invasiveness of the improvement interventions [17], the proposed strategy envisages the execution of works which are capable of increasing the resistant capacities of the building as a whole, and local operations only on the residual vulnerabilities, with targeted and localized interventions.

Following this principle, the reasoned insertion of new reinforced concrete walls that support the frames in resistance to horizontal actions and the reduction of dis-

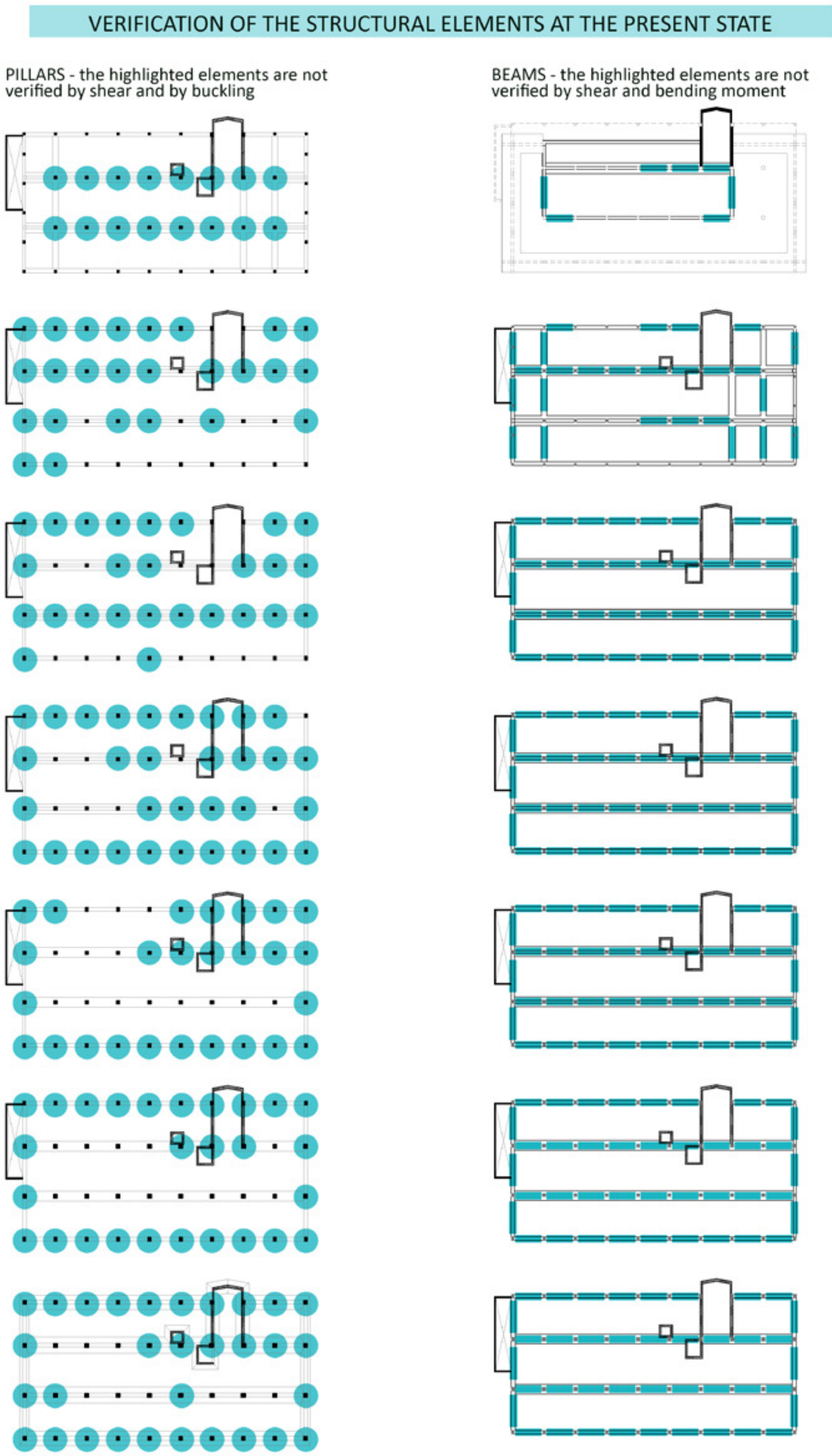


Fig. 6. *Not verified structural elements by shear, buckling and bending moment.*

placements was assessed. This allows a high increase in rigidity, given to the entire structural system [18].

A second possibility aimed at improving the seismic resistance capacity is constituted by the insertion of steel reinforcing braces within the structural spans of the reinforced concrete frame [19]; this strategy appears to be the most appropriate intervention for frame buildings with pillars of reduced cross-section, which are slender and flexible, and allows to reduce the construction times if compared to the integration of new reinforced concrete elements [20]. The braces are added to the pre-existing structural scheme in a less invasive way than the shear walls; in fact, while for the latter it is also necessary to create a new foundation, with steel braces this is not necessary, as they are connected with joints to the pre-existing structure, ensuring a remarkable simplicity of construction.

One aspect to be carefully evaluated for this type of intervention, however, concerns the more complex design of the stiffening structure, which must be correctly braced, considering the local instability phenomena of the compressed elements and trying to favor a collapse due to the yield stress of the tense elements [21].

The aim is to add rigid and resistant elements which are capable of absorbing the seismic action and relieving the most vulnerable elements, such as reinforced concrete beams and pillars, while not drastically transforming the structural behavior. However, this strategy can induce considerable additional stresses in the structural nodes, which often require punctual reinforcements in order not to generate local collapses. It is possible to reduce excessive axial forces between the bracing system and the reinforced concrete frame by creating an internal counter-frame connected along the perimeter, thus ensuring the adequate transmission of the stresses and avoiding their concentration in the nodes.

From the distribution point of view, the steel stiffeners are suitable for buildings where the maintenance of the current use of free and open rooms is necessary, as is the case on the ground floor of the Agip motel, where

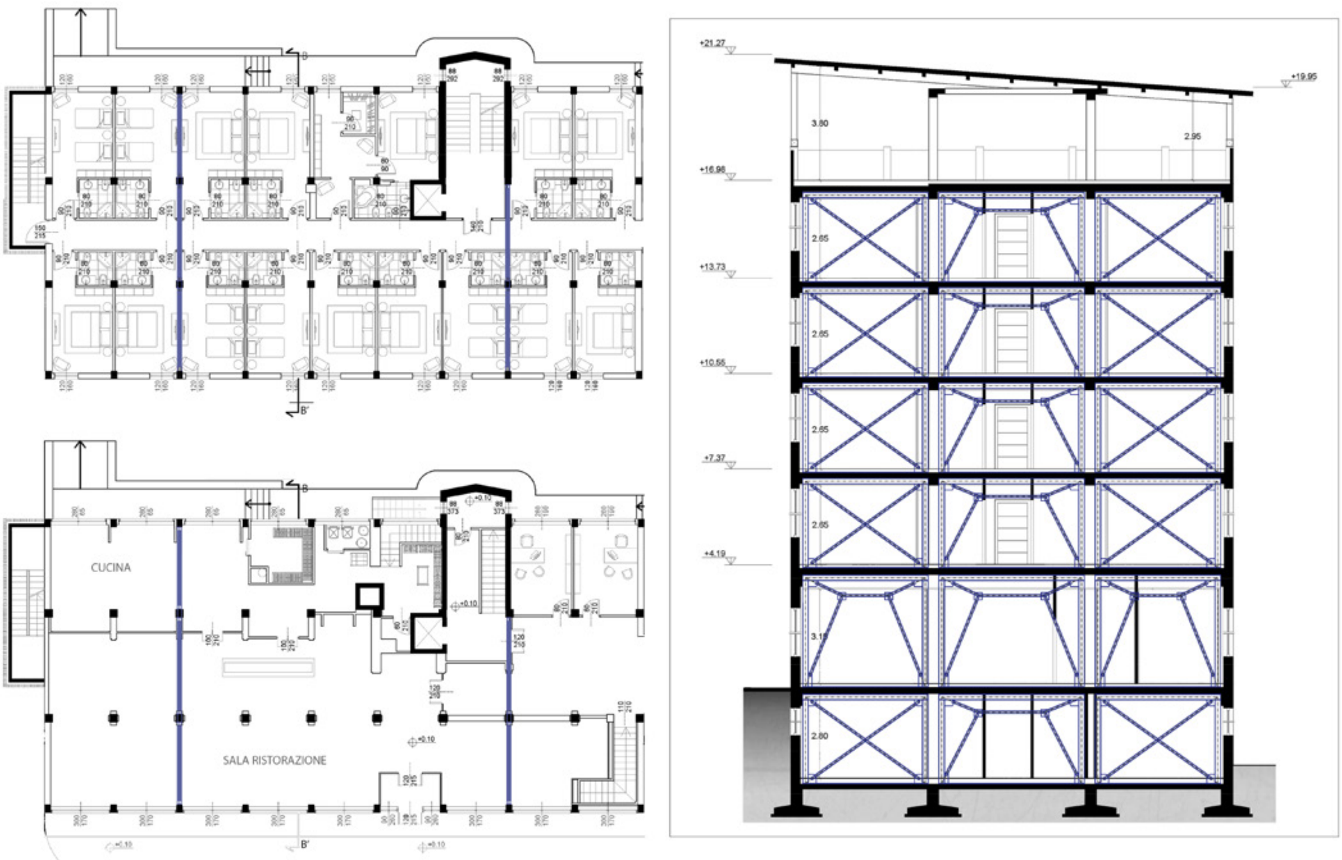


Fig. 7. *In blue, on the left: the proposed arrangement of the steel braces on the ground floor and standard floor plan; on the right: the arrangement of the steel braces in elevation.*

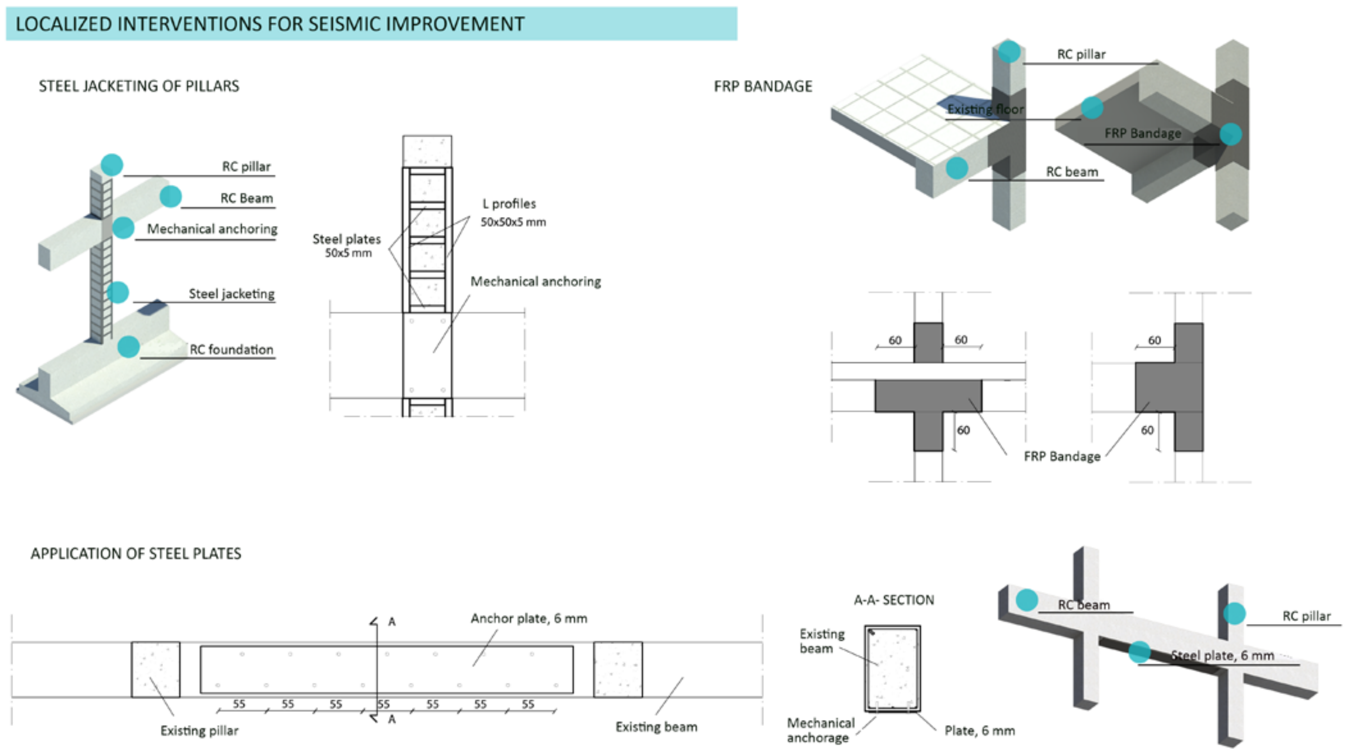


Fig. 8. *Hypothesis of localized interventions for residual vulnerabilities.*

the restaurant is located. The insertion of cross braces in the portions that do not need to remain open, together with K braces in the free portions, allows to achieve a regular distribution of the stiffening elements, without substantially altering the usability of the internal spaces (Fig. 7 and Fig. 8).

7. CONCLUSIONS

The reconciliation of performance improvement with the requests related to the protection of buildings as evidence of the built heritage of the 20th century is a complex activity, which requires the search for a balance between conservation and future interventions, in a close relationship between the will to ensure continuity of use and fulfillment of performance requirements related to structural safety.

Abandoning the idea of defining an intervention project simply on the application of codified rules, as happens for new buildings, the knowledge of the construction characteristics of this heritage must guide the choices, with quantitative assessments to be used as support tools in order to acquire a deeper awareness.

When it is necessary to intervene on existing buildings with a reinforced concrete frame that has been designed for static loads only, the resistant structural system generally consists of frames organized in one direction only and with the lack of connecting beams between the frames. The connection is carried out only through the floors, which do not have the proper stiffness characteristics due to the absence of the load distribution slab. This structural concept is unsuitable for seismic actions and requires interventions in order to make an adequate bracing system for horizontal actions in both directions.

In order to achieve the maximum compatibility and the minimal invasiveness of the improvement interventions, the most appropriate strategy is the execution of global actions, able to increase the resistant capacities of the building as a whole, and operating locally only on the residual vulnerabilities with localized interventions.

This includes the choices to integrate the existing structure with new stiffening systems with reinforced concrete walls, but also the insertion of metal bracings, much more suitable if the original structure is equipped with vertical elements having a reduced section and high flexibility.

6. REFERENCES

[1] Hobsbawm EJ, (1985) Il secolo breve. Rizzoli, Milano

[2] Li Vigni B (2014) Enrico Mattei. L'uomo del futuro che inventò la rinascita italiana. Editori Riuniti University Press, Roma

[3] Bovo F (2016) Enrico Mattei: l'uomo della rinascita. Vita e morte dell'ultimo patriota. Anteo Edizioni, Reggio Emilia

[4] Meduni E (1999) L'Autostrada del Sole. Il Mulino, Bologna

[5] Greco L (2010) Architetture autostradali in Italia. Progetto e costruzione negli edifici per l'assistenza ai viaggiatori. Gangemi, Roma

[6] Greco L, Mornati S (2018) Architetture Eni in Italia (1953-1962). Gangemi, Roma

[7] Deschermeier D (2008) Impero Eni. L'architettura aziendale e l'urbanistica di Enrico Mattei. Damiani, Bologna

[8] Severati C, Merlo M (2005) Edoardo Gellner: architetture organiche per Enrico Mattei, 1954-1961. Atti della giornata di studi, Roma, Gela, Pieve di Cadore, Sala Herzog, Facoltà di architettura, Roma Tre, 17 marzo 2005

[9] Bagnolo V, Rosas M (2020) The Decommissioned Petrol Station in Piazza Manno in Oristano (Italy). In: Agustín-Hernández L, Vallespín Muniesa A, Fernández-Morales A (eds) Graphical Heritage. EGA 2020. Springer Series in Design and Innovation, vol 5. Springer, Cham, pp 224–236

[10] Greco L (2012) La Snamprogetti negli anni '50 e '60 in Italia. Note sull'attività di un servizio di progettazione edilizia. In: D'Agostino S (a cura di) Storia dell'Ingegneria. Atti del 4° Convegno Nazionale. Cuzzolin Editore, Napoli, pp 943–954

[11] Mornati S (2015) Marco Bacigalupo e Ugo Ratti, architetti dell'ENI: il palazzo direzionale a Metanopoli. L'Industria delle Costruzioni 445: 110–113

[12] Greco L (2011) Il primo palazzo per uffici Eni a San Donato Milanese. L'Industria delle Costruzioni 420: 111–113

[13] Predari G (2015) I solai latero-cementizi nella costruzione moderna in Italia. 1930-1950. Bononia University Press, Bologna

[14] Santarella L (1964), Il cemento armato. Volume secondo. Le applicazioni alle costruzioni civili ed industriali. Hoepli, Milano

[15] Erredibi Piacenza (1966) Manualetto Erredibi. Murature – Solai – Coperture – Capannoni Prefabbricati. Sesta edizione riveduta e aggiornata. Arti Grafiche Callegari, Milano

[16] Lombardo S (2018) Valutazione della vulnerabilità sismica degli edifici esistenti in cemento armato. Aggiornato alla NTC 2018. Flaccovio, Palermo

[17] Lombardo S (2018) Manuale degli interventi di riparazione, miglioramento e adeguamento sismico di strutture in cemento armato. Tecniche tradizionali e moderne. Flaccovio, Palermo

[18] Borriero M, Mpampatsikos V (2011) Riqualificazione strutturale di edifici in calcestruzzo armato. Maggioli Editore, Santarcangelo di Romagna (RN)

[19] Lippi FV, Mangini F, Salvatore W. Caprili S (2018) L'acciaio negli interventi strutturali su costruzioni esistenti di muratura e di calcestruzzo armato: esempi ed applicazioni. Redatto ai sensi delle norme tecniche per le costruzioni 2018. Flaccovio, Palermo

[20] Gulli R, Predari G (2018) Il Moderno a Bologna: la Facoltà di Ingegneria di Giuseppe Vaccaro (1932-1935). ANANKE 83: 101–108

[21] Buttarelli F, Dell'Asta A (2015) Protezione sismica di edifici esistenti in c.a. con controventi dissipativi in acciaio. Flaccovio, Palermo

DESIGNED FOR MACHINES. ITALIAN BRIDGES AND VIADUCTS (1965-1990)

TEMA
Technologies Engineering Materials Architecture
e-ISSN 2421-4574
Vol. 6, No. 2 - (2020)

Gianluca Capurso, Francesca Martire

DOI: 10.30682/tema0602d

Highlights

During the sixties, the aim of reducing the production time and costs made it impossible to postpone in Italy the mechanisation of building sites and the industrialisation of construction processes of bridges and viaducts. The Italian building site abandoned the artisanal dimension, and the character of the works was irreversibly transformed. Triumphant were the free cantilever bridges, the viaducts made of high piles and beams, the precast modules, and the hyper-technological self-launching falseworks. The building fervour dissolved the identity of the Italian School of Engineering, which only a few solitary talented designers tried to keep alive.

Abstract

This contribution is a result of the researches, carried out by the authors as part of the SIXXI project - History of Structural Engineering in Italy in the 20th Century (ERC Advanced Grant, PI Sergio Poretti, Tullia Iori - www.sixxi.eu), about the transformation of Italian Engineering after the second half of the sixties. It reconstructs the evolution of the building systems introduced in the building sites of bridges and viaducts, from the presentation of industrial patents to the first applications abroad and then by national designers and companies, to examine what impact they had on the production of Italian engineering.

Keywords

Mechanisation, Infrastructures, Viaducts, SIXXI research project, History of Engineering.

Gianluca Capurso*
DICII - Dipartimento di Ingegneria Civile e Ingegneria Informatica, Università di Roma Tor Vergata, Roma (Italy)

Francesca Martire
DICII - Dipartimento di Ingegneria Civile e Ingegneria Informatica, Università di Roma Tor Vergata, Roma (Italy)

** Corresponding author:*
e-mail: capurso@ing.uniroma2.it

1. INTRODUCTION

Within the SIXXI project, currently in progress at the University of Rome Tor Vergata, (ERC Advanced Grant, PI Sergio Poretti, Tullia Iori - www.sixxi.eu), aiming to reconstruct the history of structural engineering in Italy in the twentieth century [1], one dedicated research has been focused on understanding how and why, in Italy, after the completion of the “Autostrada del Sole”, the infrastructure construction sector underwent a deep transformation [2].

The attention was therefore focused on the introduction of new technologies in bridge and viaduct construction sites, starting from the mid-1960s, which, in addition to guaranteeing considerable time savings, allowed labour savings for the construction of deck structures. These were, to a large extent, methods imported from abroad. Also for this reason, to tell the story of infrastructure construction in Italy in those years, one cannot help but look beyond borders.

By aiming to understand the international framework, a general survey has been carried out using the technical literature of the time and some more recent studies such as [3] and [4], enriched by some investigations on the archives of foreign companies and public bodies. To analyse the construction of Italian works, the explorations on the archives with which the SIXXI team had already established valuable synergies for studies on the history of structural engineering, were combined with research on other documentary and photographic archives, of companies and designers chosen among those most involved in the use of advanced technologies on national construction sites.

The contribution reconstructs the evolution of the various systems introduced in the construction sites, from the presentation of industrial patents to the first experimental applications abroad and then by national designers and companies, to examine what impact it had on the production of Italian engineering.

2. CLONE EFFECT

On July 6, 1950, Ulrich Finsterwalder, an engineer at the company Dyckerhoff & Widmann AG (Dywidag) and an expert in pre-stressing reinforced concrete, presented an innovative patent, No. 4931, in West Germany for the construction of “highly stressed reinforced concrete load-bearing structures, particularly in the form of bridge constructions”. In the patent, the pre-stressing induced in concrete with post-tensioned reinforcement is exploited within a new construction process that allows doing without the traditional type of temporary works. In fact, it makes it possible to “hold” the deck in balance, suspended in the void, supporting it from the abutments.

Dywidag immediately applied the system for the 62-metre span bridge over the Lahn (1950-1951) in Balduinstein. The bridge cantilevered from the two abutments at the rate of one “ashlar” per week. In each ashlar, which is three metres long, the threaded rods, produced by the same company, pre-stressed the concrete by compensating the bending moment generated by the cantilever configuration until the central ashlar was built.

The technique proved to be particularly efficient. In just a few years, Dywidag proposed it again for increasingly demanding works and between 1962 and 1964 built by means of this technique the 208 metres-span Bendorf Bridge over the Rhine (Fig. 1). In Europe, a real cloning phenomenon of the “Dywidag bridges” was triggered. They were built in Austria, Norway, Holland, and Sweden, also thanks to partnerships with other companies and the sale of the use of the patent (Fig. 2).

From the beginning of the 1960s, other European companies also began to exploit the cantilever method, also called, in French words, “*peau-à-peau*”. The object of the German patent, on the other hand, was not a specific machine or technology, but rather a constructive process that, therefore, any company could reinvent by adapting the different pre-stressing systems commercially available.

In Italy, some engineers began to experiment with the new technology, convinced that the pre-stressing of concrete mix is the winning weapon to challenge steelwork.

Riccardo Morandi, for example, chose the “*peau-à-peau*” method for the bridge over the Polcevera, whose construction site began in 1961. By using his own patent

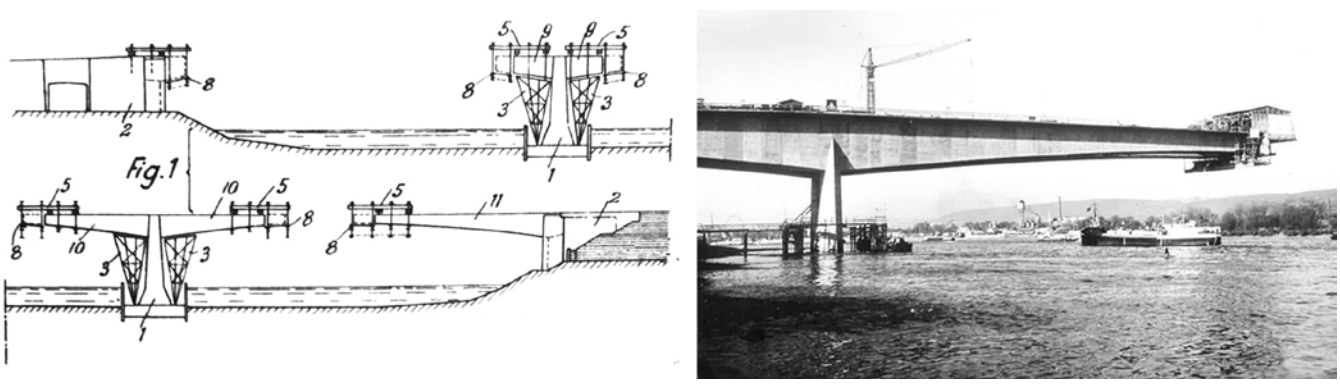


Fig. 1. *Dywidag, Italian patent n. 476948, “Procedimento per la costruzione di ponti con grandi distanze fra gli appoggi, in cemento armato”, June 30 1951 (Archivio Centrale di Stato, Rome); Bendorf bridge under construction.*

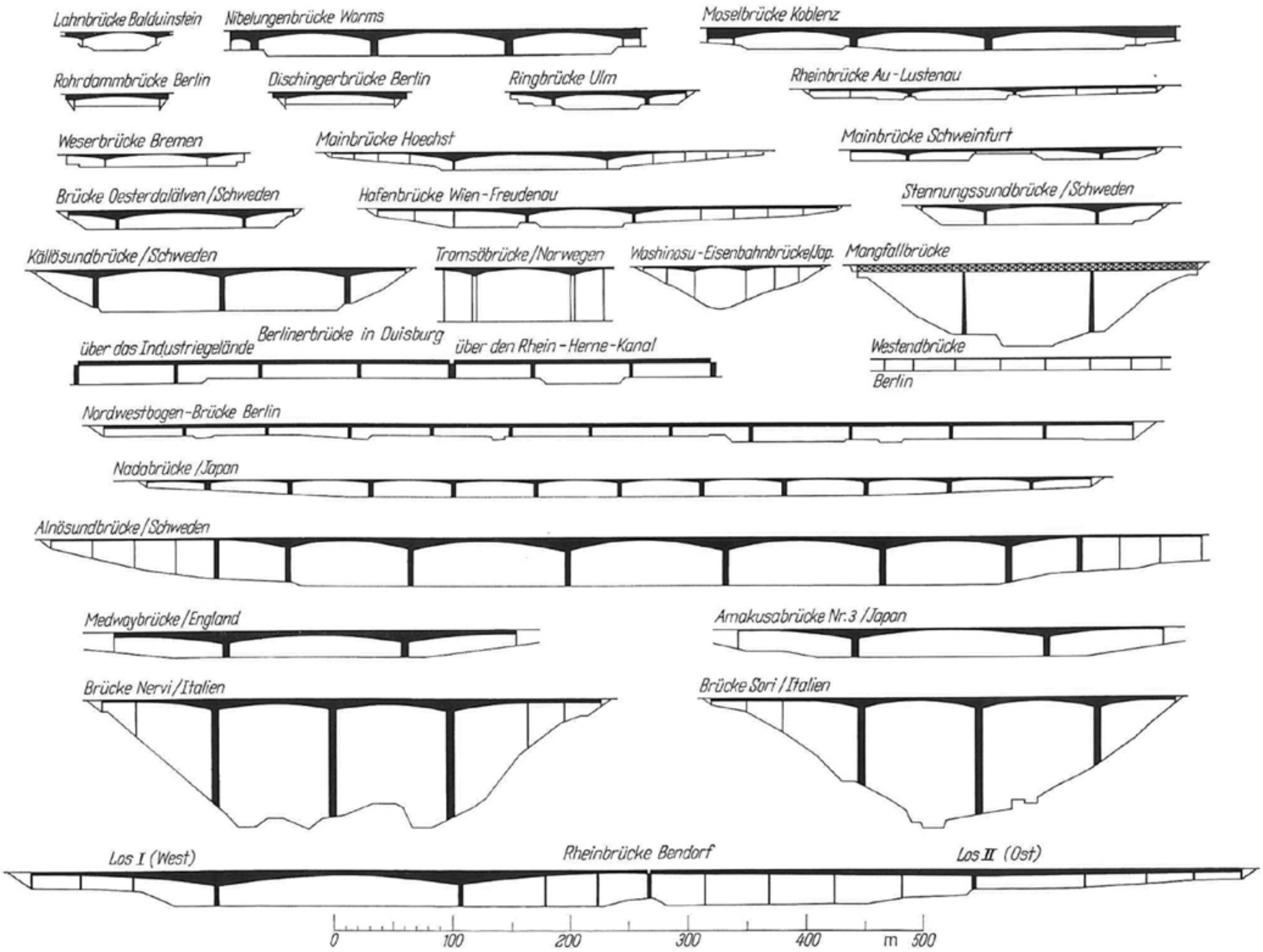


Fig. 2. *Scheme of the evolution of bridges built by the Dywidag cantilever system between 1950 and 1967 ("Dywidag Berichte", 4, 1967).*

for the pre-stressing of harmonic steel wires, the method allowed the girders to be supported without ribs, so as not to interrupt the traffic of the railway park below, until the girder, almost complete, could finally be anchored by the final tie rods [5].

Silvano Zorzi also explored the possibilities of the technique, applying the Dywidag patent to the viaducts of the Genoa-Sestri Levante motorway that cross the Nervi, Sori and Veilino torrents (1963-1965). The bridges have spans ranging from 70 to 100 metres and reach an altitude of 100 metres at the bottom of the valley, being three of the highest built with the original Dywidag system. The Autostrade Company's projects initially included sequences of parabolic arches, but the Superintendence of Liguria rejected the solution because of its impact on the landscape.

The cantilever system, therefore, convinced Zorzi, in charge of the new executive design, for the low rate of workforce required, evident if this site is compared to the very crowded ones on the Autostrada del Sole, a few years earlier.

An analysis of the project's prices reveals [6], anyway, the considerable impact, on the cost of the works, of dismantling the equipment from a pile, transporting it down, pulling and reassembling it on the next pile: the problem stimulated the search for even more convenient solutions, as will be seen hereinafter.

Outside the country, also the less famous Italian engineer Alfredo Passaro decided to test the free cantilever, using it for the Shambat Bridge over the Nile in Khartoum, Sudan (1962-1965) [7]. With the Recchi Company, however, Passaro chose the Freyssinet pre-stressing system, and the firm purchased directly from STUP – the company founded by the French engineer – the sliding formwork for casting the ashlars.

After the first experiments, the "free cantilever" system, particularly suitable for spans of over 70 meters and

Fig. 3. *Ferrata Viaduct at Cineto Romano, Rome-L'Aquila motorway, A. Gervaso, 1969-1970. San Cosimato Viaduct on the river Aniene, Rome-L'Aquila motorway, A. Gervaso, 1969-1970 (Amedeo Gervaso Private Archive, Lugano); Incoronata Viaduct at Polla, Salerno- Reggio Calabria motorway, A. Passaro, 1967-1968 (Alfredo Passaro Private Archive, Napoli).*

up to 200 meters, was successful in the typical field of application of the arc solution. The cantilevered bridge, with its characteristic beam shape with a variable section, with a curved intrados that indicates the origin of two shelves, thus became the leitmotiv in the most demanding crossings of the Italian motorway network, of which, since 1964 and in about ten years, more than 5,000 kilometres were built [8]. On the many new motorways and expressways, the structural engineers most experienced such as Amedeo Gervaso [9], Alfredo Passaro, Lino and Bruno Gentilini and Giorgio Belloni, as well as Zorzi and Morandi, designed bridges with the cantilever system, with ever-increasing spans.

In the absence of originality, all the projects seem to speak a single, foreign language, conditioned by the construction system (Fig. 3). The glorious Italian School of Engineering [1], suddenly, looks like it was in difficulty and struggling to express the identity that distinguished it during the years of Reconstruction and the economic miracle.

Exceptions are some attempts to customise the product, for example by modifying the look of the piles, with specially designed variants of self-erecting formwork systems, as in the Colle Isarco viaduct on the Brenner Motorway [10], designed by the two Gentilini brothers, or by emptying the lower slab of the girder, as Zorzi did in the Bisagno viaduct (1966-1967). Among the attempts of the Paduan engineer to preserve the identity of the School, two works certainly stand out: the bridge over the Tagliamento at Pinzano (1968-1970), where the initial cantilevered configuration adopted during construction was finally transformed into a perfectly proportioned three-hinged arch structure, and the viaduct over the Gorsexio stream for the Voltri-Alessandria motorway (1971-1978), where he completely redefined the relationship between the girders and the supports, thanks to the introduction of lamellar piles at the top [11].

3. BRIDGES AND CONSTRUCTION SITES IN MOTION

In the 1960s, construction companies began to master the new cantilever technique. This extended the bridge spans that could be built without using the arch, now an illustrious pensioner. The all-steel solutions, traditionally not part of the Italian construction site, were chosen for the execution of exceptionally demanding works, such as the viaducts on the Lao (1964-1970) and the Sfalassà (1970-1972) of the Salerno-Reggio Calabria motorway. The simpler crossings, with smaller spans, less than 45 metres and spread over all the sections, became the preferred field of application for prefabricated decks, almost exclusively pre-stressed, in the version of the isostatic truss on two supports.

Soon, however, engineers and construction companies began to notice the monotony and some inefficiency of traditional prefabricated solutions. The former tried to avoid the boring image of the infinitely repeated trilithon, while construction firms studied ways to reduce operations on-site and speed up the production of components, in the workshop or worked on-site to set then in place [12].

One of the most extravagant attempts was the application of the bridge launching method [13]. The idea, born

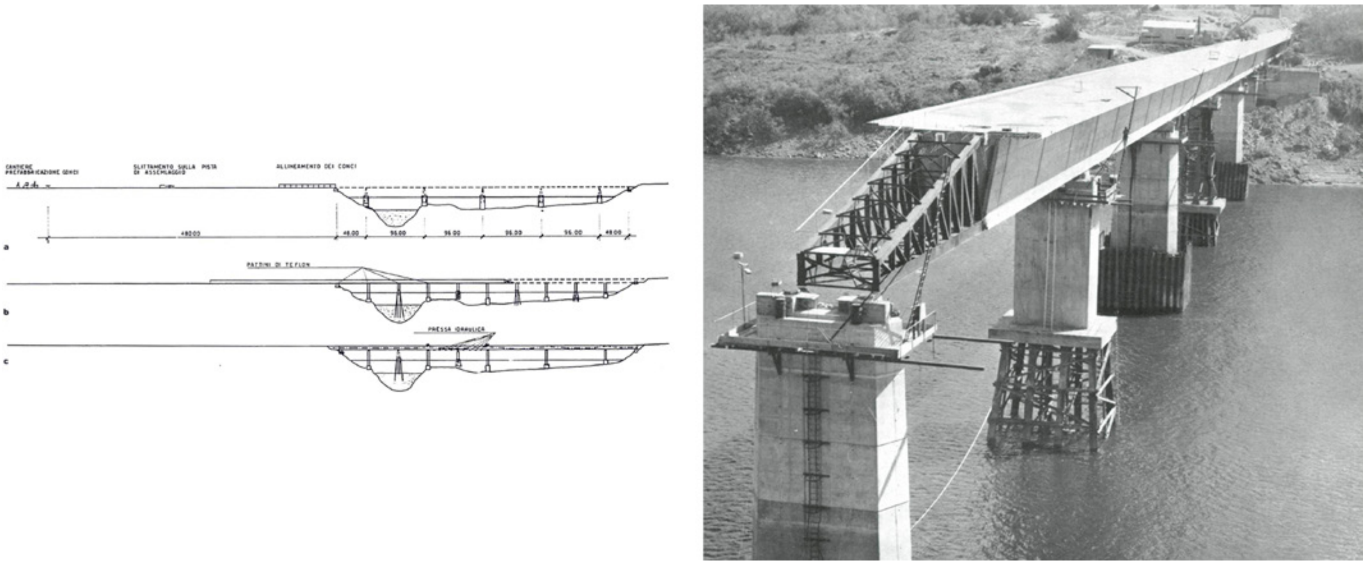


Fig. 4. *F. Leonhardt, the bridge on the Caroni River, scheme of the launching [13]; construction site.*

in the field of steel construction, is simple but was used, for the first time, in the project of a pre-stressed concrete bridge only in 1961 in Venezuela, by Fritz Leonhardt, Wolfhart Andrä and Willi Baur, for the crossing of the Rio Caroni (Fig. 4).

The system was then perfected in the construction of the Innbrücke at Kufstein in Austria (1966-1969), becoming “incremental”, as the casting of ashlar was alternated with an advance of equal length of the cast girders, with a considerable reduction of the necessary site space.

Italian companies soon became curious about the system, as demonstrated by Del Favero’s construction of the bridge over the Semorile ditch on the Genoa-Sestri Levante motorway (1967-1968), designed with the advice of the Hungarian engineer Thiamér Koncz (Fig. 5). However, despite the low rate of labour required, the modest installation costs, and the apparent simplicity of the procedure, the spread of the method was not “viral” [2].

The most important attempt to identify alternatives to prefabricated systems for the construction of bridge

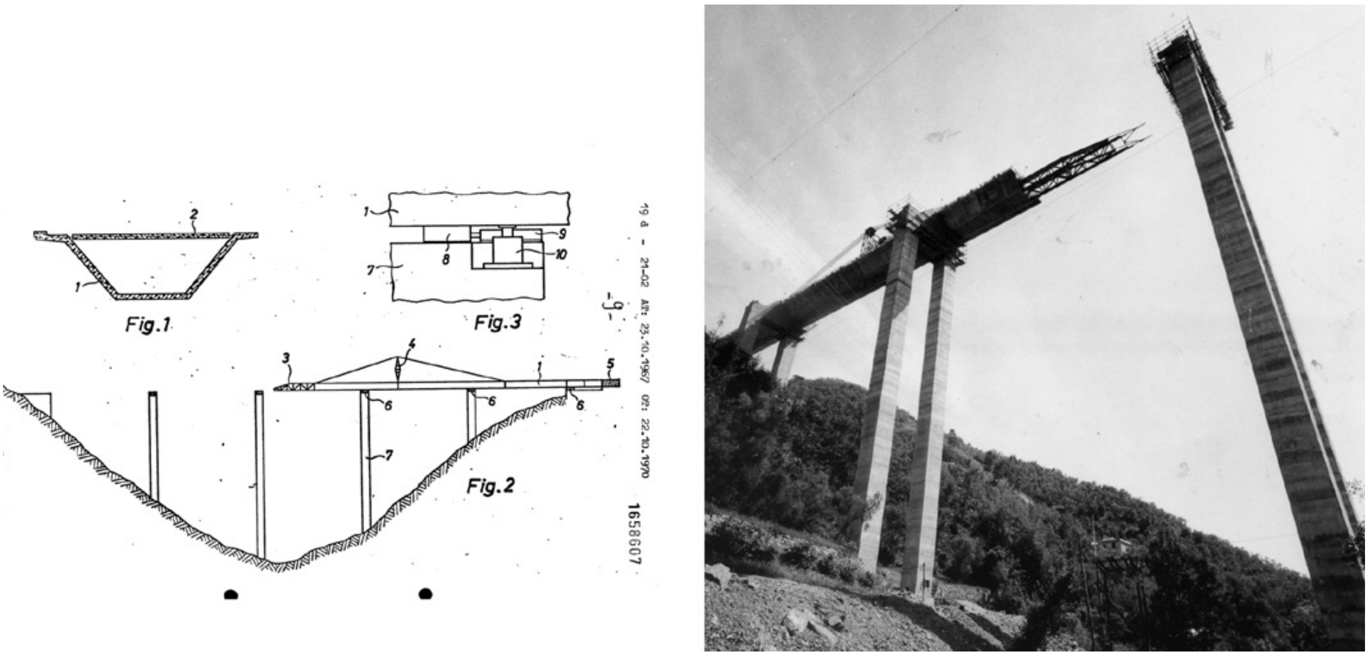


Fig. 5. *T. Koncz, German patent n. 1658607, 1967 (European Office Patent Archive). Del Favero Company, the bridge over the Semorile ditch.*

decks, however, is certainly the one that exploited the potential of the self-launching falseworks, machines that make it possible to move the formworks for the casting of decks, without interruption, at height and without temporary supports, from one pile to the next.

The German company Polensky & Zöllner and the Austrian one Strabag, who won important contracts in West Germany, made the use of these machines systematic in Europe at the beginning of the 1960s. After the construction of the first viaducts with this technology, however, it became clear that work-planning strategies had to be implemented to optimise the use of this expensive equipment. In order to amortise the costs incurred, it was necessary to reuse them on average on at least four construction sites [14]. Obviously, this affected the design of the viaducts: the more similar and standardised they were, the easier it was to reuse the equipment.

In Italy, meanwhile, the protagonist in infrastructure projects was no longer the bridge – an object completed and placed on the single crossing – but the long, very long viaduct, developed up to tens of kilometres, whose proportions remain difficult to perceive. The viaduct was used as an urban overpass, to solve traffic problems, and as a substitute for the embankment on expressways. In cases where the project foresees many spans of constant width, not exceeding 50 metres, the use of the self-launching falsework was effectively competitive [15].

The one who interpreted the use of these sliding machines in the most refined way was Zorzi, which always used the most up-to-date technology to guarantee competitiveness to its design proposals [16, 17].

In those years, he was looking with interest at the very efficient German falseworks and to the mushroom-shaped viaducts made with a new type of translating device, patented by Dywidag and used by Finsterwalder, for the first time, in the viaduct over the Elz valley between Kehrig and Kaifenheim [18].

The "Dywidag type" machine allowed the formwork to be shaped freely, hanging from the metal ribs surrounding the casting square (Fig. 6). Zorzi used it, at the

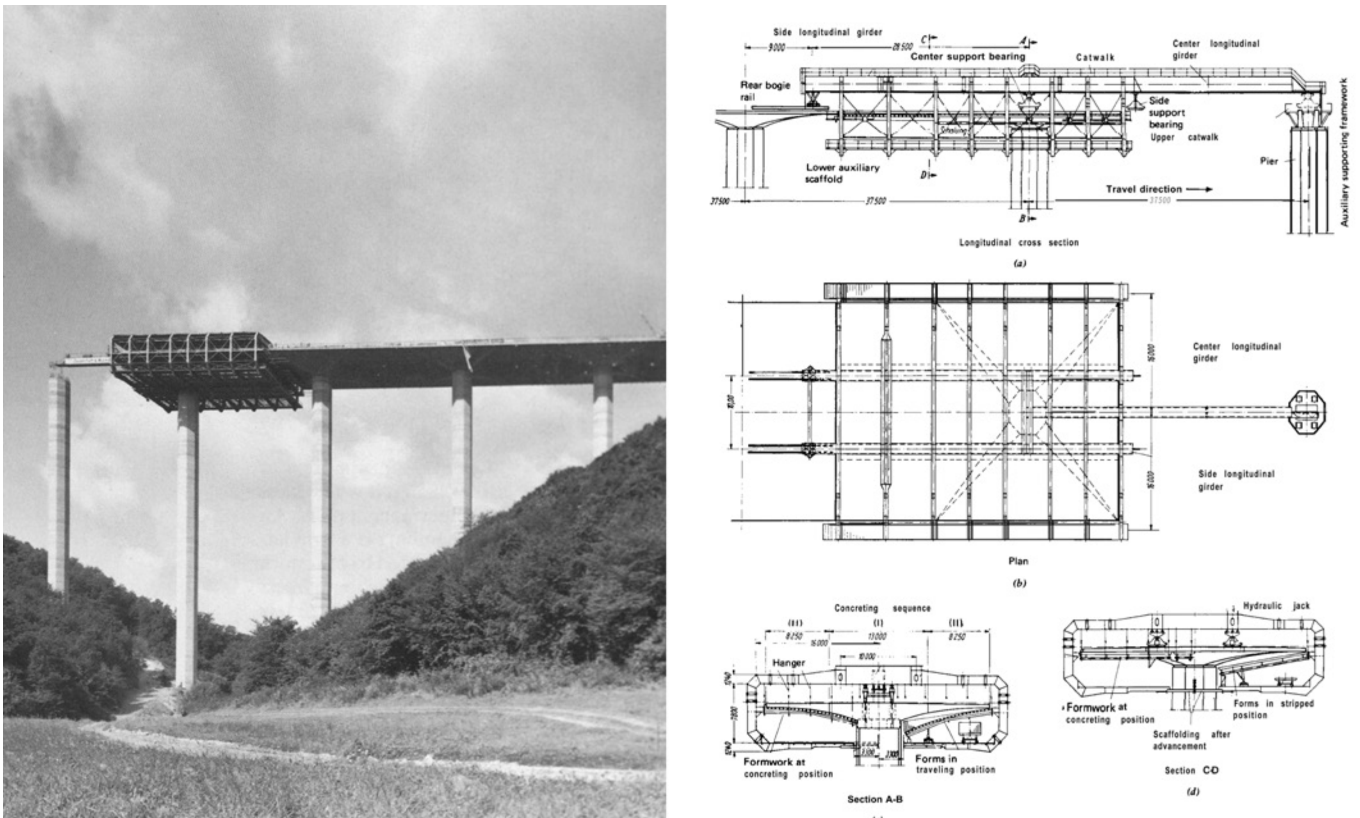


Fig. 6. *U. Finsterwalder, Dywidag, viaduct on the Elztal between Kehrig and Kaifenheim, Germany, 1964-1965, view during construction and scheme of the self-launching falsework.*

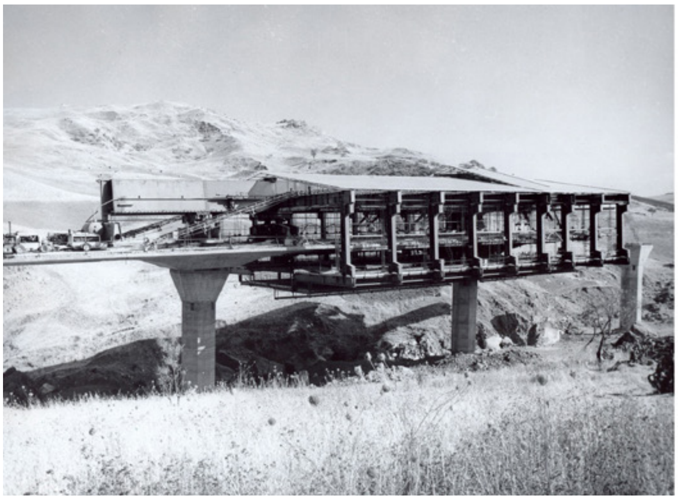


Fig. 7. *S. Zorzi, Fichera viaduct, Palermo-Catania motorway, 1971-1972, self-launching falsework (Inco Archive, Mendrisio); view from below (De Col Engineers private archive, Belluno).*

first opportunity, for the 7 kilometres of the Fichera viaduct (Fig. 7) on the Palermo-Catania motorway (1971-1972) [16].

Fig. 8. *S. Zorzi, L. Lonardo, Viaduct on the Teccio river, Torino-Savona motorway, 1973-1976 (photo by Sergio Poretti, SIXXI Archive, University of Rome "Tor Vergata").*

The most elegant and at the same time spectacular result, however, appears today the viaduct over the Teccio, for the doubling of the Turin-Savona motorway (1973-1976). On a sequence of very high piles, made transparent thanks to the expedient of the lamellar supports already used in the viaduct over the Gorsexio, the machine was launched at dizzying heights and drew a very thin pre-stressed ribbon (Fig. 8).

Zorzi then tested the system on a large scale in the third mainland bridge over the Lagos Lagoon (1976-1980), in Nigeria, built by a Joint Venture led by the local branch of Borini & Prono. It confirms Zorzi's attempt to preserve the quality of the viaduct's design even outside Italy, in countries where it was apparently impossible to propose a formally refined project, using entirely mechanised construction procedures (Fig. 9).

Fig. 9. *S. Zorzi, third mainland bridge over the Lagos Lagoon, Lagos, Nigeria, 1976-1980 (Inco Archive, Mendrisio).*

4. PREFABRICATION AND OTHER STORIES

Despite the interest aroused by the self-launching false-works, their application was limited, in Italy, mainly to works inserted in special environmental or urban contexts, and to Zorzi's solitary research [15].

The major Italian construction firms, which in those years joined together to dedicate themselves also to the building sites of the Rome-Florence express railway, aimed instead at perfecting the prefabrication techniques of the decks.

The experience of the Ferrocemento company and one of its structural engineers, Pellegrino Gallo, is emblematic [19, 20]. On the Rome-Florence "Direttissima" railway, the company built the Montallese viaduct (1980-1981), over two and a half kilometres long, and then the Faella, Riofi, San Zeno and Chiana viaducts (1986-1990), for a total length of 8 kilometres, with giant single-cell box modules, each capable of covering spans of 25 metres (Fig. 10). These decks, entirely produced in the workshop, were the result of studies and research conducted by the company since the end of the fifties, in which a strategy of progressive reduction of the operations to be carried out to build bridges and viaducts had been put in place. In the eighties, the executive procedure was perfected to such an extent that the production and installation of modules were achieved, at the rate of four spans in 5 working days.

In the meantime, the lack of long-term planning on roadworks was discouraging large investments in such expensive equipment. For this reason, also construction companies in Italy began to adopt cantilever building techniques based on the assembly in situ of prefabricated segments.

The technique, which originated from Freyssinet's experiments at the turn of World War II, was perfected by Jean Muller in the small bridge at Shelton, near New York, introducing the "match-casting" procedure [2]. In just a few years, the technique became so reliable that it could be used in the construction of the Chillon Bridge in Switzerland (1966-1969): its sinuous, variable-profile deck is the result of the assembly of 1376 prefabricated elements glued with epoxy resin [21].

Compared to these experiences, particularly advanced, in Italy, the technique was introduced and spread with years of delay. Abroad, however, it was applied by the companies Ferrocemento, Impresit, Girola and Sideco SACIC for the construction of the central span of the remarkable 245-metre span of the "General Manuel Belgrano" bridge over the Rio Paranà (1968-1973), using a new mineral material, the "tixojoint", instead of the epoxy resin.

It was only in the Eighties that we finally saw large-scale applications on Italian construction sites. In particular, on the Udine-Carnia-Tarvisio motorway, prefabricated segments gained considerable success because

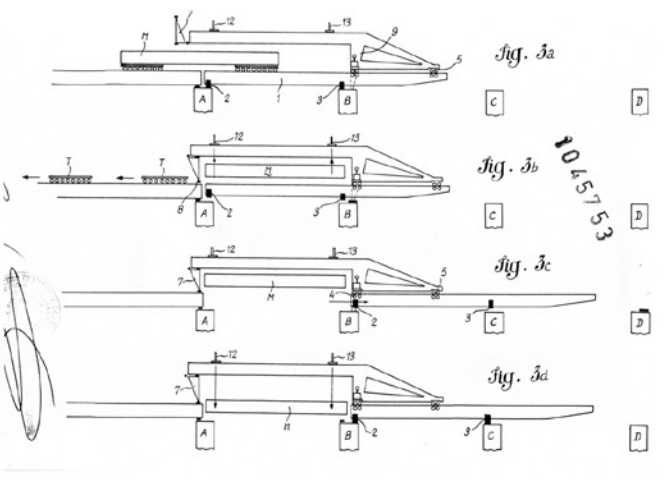


Fig. 10. *Ferrocemento, P. Gallo, patent n. IT1045753, "Procedimento e dispositivo per il varo in opera di impalcati prefabbricati costruiti in un pezzo unico monolitico", December 21 1972; transportation of the giant decks of the S. Zeno viaduct, Rome-Florence "Direttissima" railway, 1986-1990 [20].*

they made it possible to select the optimal solution freely with the minimum cost between different span sizes and number [23].

5. EPILOGUE

In the 1990s, research seemed to focus more on improving the mechanical characteristics of materials and their durability, given the problems that emerged in the management of existing infrastructure, in some cases suffering from rapid degradation. It is no coincidence that Mario Paolo Petrangeli, in those years, elaborated and publicised the theory of the machine bridge, whose parts could easily be replaced at the end of their useful life [24].

On the construction sites, the systems developed over the previous three decades were continuously being improved. In some cases, there was a remake of some of the most successful works designed by Zorzi, such as the Fadalto motorway viaduct (1988-1990) and the one on the Bormida valley (1998-2000). On their own construction sites, the State Railways preferred isostatic solutions, thanks to the adoption of the “long welded rail”, decreeing the success of the giant prefabrication, of which the “Modena viaduct system” (2002-2006) for the High-Speed Milan-Bologna Line represents one of the most significant applications [25].

6. CONCLUSIONS

The investigations carried out have made it possible to reconstruct the transformation of the infrastructure sector from the 1960s to the 1980s, helping to shed light on the history of Italian engineering in this period.

In particular, from the study presented, it emerges how the introduction of new technologies, modern and advanced, irreversibly changed the approach to the design of the large structure and how the national yard completely abandoned its artisan dimension. The choice of structural schemes and shapes is no longer determined by the static solutions in operation, but by the construction systems and equipment used for prefabrication, handling, laying, or casting. The traditional building site, in which it had been possible to create unique pieces, was transformed into a mechanised factory, where work times and procedures were increasingly similar to those of an industrial production chain.

Together with other factors linked to public works policy in the same years, mechanisation influenced the progressive homologation and standardisation of viaducts, which now extend as far as the eye can see. In the operational fervour of these years, the identity of the Italian School of Engineering and the Made in Italy product, which only a few solitary talents tried to survive, suddenly dissolved.

6. REFERENCES

[1] Iori T, Poretti S (2016) Storia dell’ingegneria strutturale italiana. Ascesa e declino. In: Iori T, Poretti S (eds) La Scuola italiana di ingegneria, monographic issue of Rassegna di Architettura e Urbanistica 148: 8–52

[2] Capurso G, Martire F (2017) Cantieri nel vuoto. Viadotti in cerca d’autore. In: Iori T, Poretti S (a cura di) SIXXI 4. Storia dell’ingegneria strutturale in Italia. Gangemi, Roma, pp 98–115

[3] Wittfoht H (1984) Building Bridges. History, Technology, Construction. Beton-Verlag, Düsseldorf

[4] Podolny Jr. W, Muller J (1979) Construction and Design of Prestressed Concrete Segmental Bridges, John Wiley & Sons, New York

[5] Morandi R (1967) Il viadotto sul Polcevera per l’autostrada Genova-Savona. L’industria Italiana del Cemento 12: 849–872

[6] ANAS Archive, Rome (1963) “Progetto esecutivo dei viadotti sui torrenti Veilino, Nervi, Sori – Relazione generale”. September 4, box n. 1255671

[7] Ponte sul Nilo a Khartoum nel Sudan (1966) In: Realizzazioni italiane in cemento armato precompresso 1962-66, V Congresso Internazionale del Precompresso (FIP) – Parigi 1966. AITEC, Roma pp 171–177

[8] Macchi G (1970) Ponti e viadotti. In: Realizzazioni italiane in cemento armato precompresso 1966-70, VI Congresso Internazionale del Precompresso (FIP) – Praga 1970. AITEC, Roma pp 11–18

[9] Monfrecola T (2015) L’Ingegneria strutturale italiana dopo il miracolo: l’opera di Amedeo Gervaso [“Ingegneria dell’Edilizia” Bachelor Degree Thesis]. Rome: Università di Roma “Tor Vergata”. Supervisor: T. Iori, co-supervisor: G. Capurso, F. Martire

[10] Fondazione Ing. Lino Gentilini Archive, Trento

[11] Viadotto sul torrente Gorsexio per l’autostrada Voltri-Alessandria (1978). In: Realizzazioni italiane in cemento armato precompresso 1974-78, 8° Congresso Internazionale del Precompresso (FIP) – Londra 1978. AITEC, Roma, pp 11–18

[12] Gallo P (1988) La prefabbricazione strutturale: aspetti applicativi (1988). In: Giornate AICAP '87. Stresa 23-25 aprile. Atti del convegno. AICAP, Roma

[13] Leonhardt F (1967) Il ponte sul rio Caroni in Venezuela. L'industria Italiana del Cemento 11: 761–784

[14] Wittfoht H (1967) Nuove attrezzature per la costruzione degli impalcati dei ponti in cemento armato precompresso in Germania. L'industria Italiana del Cemento 9: 595–618

[15] De Miranda F, Gallo P, Nascè V, Vignudelli F, Zorzi S (1977) Le costruzioni metalliche nella meccanizzazione dei cantieri. Macchine e strutture ausiliarie per la costruzione di viadotti in c.a.p. e in acciaio. Costruzioni metalliche 1: 1–15

[16] Blandino I (2012) I viadotti di Silvano Zorzi. Sperimentazioni strutturali e costruttive tra gli anni Sessanta e gli anni Settanta ["Ingegneria Edile: Architettura e Costruzione" PhD Thesis]. Rome: Università di Roma "Tor Vergata", 2012. Supervisor: S. Poretti, T. Iori

[17] Zorzi S (1980) Ponti a travata realizzati con centine auto varanti. L'industria italiana del cemento 11: 399–424

[18] Casado CF (1966) Los puentes de fabrica durante el año 1965. Revistas de Obras Pùblicas 3018: 821–835

[19] Condotte Spa Archive, Rome

[20] Pellegrino Gallo Private Archive, Rome

[21] Der Viadukt von Chillon VD (1972) Das Werk 59: 274–276

[22] Riccardo Morandi Fonds, National Central Archive, Rome

[23] Faustetti F, Rovera A (1985) Impalcati a conci prefabbricati per l'Autostrada Udine-Carnia-Tarvisio. L'industria Italiana del Cemento 10: 604–625

[24] Petrangeli MP (2000) L'evoluzione dei ponti in c.a. e c.a.p. nel '900. In: Il secolo del cemento, supplemento a "L'industria Italiana del Cemento" 9: 99–120

[25] Capurso G, Martire F (2015) La crisi (in)visibile 1964-2001. In: Iori T, Poretti S (eds) SIXXI 3. Storia dell'ingegneria strutturale in Italia. Gangemi, Roma, pp 86–107

TEMA
Technologies Engineering Materials Architecture
e-ISSN 2421-4574
Vol. 6, No. 2 - (2020)

METHODS AND INSTRUMENTS FOR PREFABRICATED HOUSING REFURBISHMENT: THE FRENCH CASE (1960-70)

Angelo Bertolazzi, Agata Maniero, Giorgio Croatto, Giovanni Santi, Umberto Turrini

DOI: 10.30682/tema0602e

Angelo Bertolazzi*
ICEA - Dipartimento di Ingegneria civile, edile e ambientale, Università degli Studi di Padova, Padova (Italy)

Agata Maniero
ICEA - Dipartimento di Ingegneria civile, edile e ambientale, Università degli Studi di Padova, Padova (Italy)

Giorgio Croatto
ICEA - Dipartimento di Ingegneria civile, edile e ambientale, Università degli Studi di Padova, Padova (Italy)

Giovanni Santi
DESTEC - Dipartimento di Ingegneria dell'Energia, dei Sistemi, del Territorio e delle Costruzioni, Università di Pisa, Pisa (Italy)

Umberto Turrini
ICEA - Dipartimento di Ingegneria civile, edile e ambientale, Università degli Studi di Padova, Padova (Italy)

** Corresponding author:*
e-mail: angelo.bertolazzi@unipd.it

Highlights

This study focuses on analysing the front panels of two French patents (i.e. Balency and Camus): developed in the 60s, they were widely resorted to in Europe. The material, geometrical, and construction-related data led to implementing a BIM model that furthered the development of a methodology of digitisation of European prefabricated building stock, with a view to its upgrading, as far as architecture, environment and functions are concerned.

Abstract

The 60s and 70s housing blocks consisting of large two-dimensional prefabricated elements represent a sizable share of European building assets: their upgrading as regards architecture, energy efficiency, environment and social services is a priority for European Union aims by 2050. Prefabricated housing blocks total to such large numbers as to require new methodologies and technologies to be developed, in order to make upgrading technically viable and economically sustainable.

Keywords

Prefabrication, Refurbishment, French construction, BIM, Residential buildings.

1. INTRODUCTION AND OBJECTIVES

The 60s and 70s demographic and urban growth sped up industrialisation as regards construction, thanks to the massive resort to prefabricated reinforced-concrete elements. The urgency of EU [1] strategic objectives towards upgrading the existing building stock (namely 42% reduction of total energy consumption, 35% of greenhouse gases and of over 50% of raw materials); the need to improve the environmental, social and architectural features of many European neighbourhoods; the sheer number of such buildings (in Europe they average to 67%, in the most industrialised countries – such as France, United Kingdom, Germany, Scandinavia, and Eastern Europe – they peak to 95%) demand an innovative approach to upgrading both as far as planning and analysing are concerned, prior to tackling the project [2].

The objective of the present work – belonging to a broader project regarding upgrading European two-dimensional-elements -high-rise buildings – [3], has been the analysis of two of the main French patents (Balency and Barets), focusing on their construction-related and material features. We have started from front panels, since not only do they represent the signature features of the patents, but even the utmost complexity from a material, geometrical and construction-related point of view. This has allowed exploring even the potentialities of BIM (Building Information Modelling) in digitising prefabricated building stock. Starting from their digital reproduction, which contained all the information reporting their material, geometric, and construction-related features, perfect 3D models of such buildings have been implemented. Furthermore, thanks to the BIM potentialities, the models have been connected to the information for their graphic conversion (LOD), which has allowed the processed data of the current situation to be extracted automated. Thanks to this first step towards digital modelling, the bases have been laid for the next steps leading to upgrading, which is essential when taking into account both the number of prefabricated housing blocks and the urgency of curbing energy consumption.

2. METHODOLOGY

In order to lay down a suitable approach to building heritage, so as to streamline reclamation and upgrading plans, it is essential to analyse and thoroughly assess the technological and environmental system, as well as the building procedures it has implied. As regards upgrading existing buildings, the usual approach consists in laying down an upgrading project for an ad hoc case study that proves to be only partially capable of replication; general appraisals, on the other hand, may be formulated only after carrying out several works [4]. As far as blocks built by resorting to industrialised techniques (e.g. prefabrication) are concerned, instead, it is necessary to adjust the methodology, so as to make it fit to respond to the different logic of production. Building resorting to industrially-produced prefabricated elements has in fact followed project-and-production-based principles belonging to mechanical industry: namely a prototype was developed, then it was serially reproduced [5, 6]. That is why it is necessary to start from the general analysis of the construction systems before defining the upgrading project of individual case studies; only later will the global material and performance-related condition of the buildings be assessed. The technical characterisation (i.e. construction-related features, structural behaviour, energy performance) of the "according to project" building not only allows to spot its main flaws that may be made worse by disrepair but even to lay down the preliminary set of criteria regarding upgrading industrialised buildings; this approach will minimise the hazard of the renovation project, impacting positively on its economic sustainability.

Besides showing a particular interest in upgrading 1950-2000 housing – with the view of reaching its objectives by 2050 – the EU has been increasingly keen on finding the instruments allowing upgrading to be monitored and made technically efficient and economically sustainable. This is why Building Information Modelling (BIM) has been applied to this sector of construction, exploiting the opportunities offered by the modularity and reliability of prefabricated systems, allowing to obtain a detailed rendering of the existing technological systems, to which retrofit projects can later be connected.

3. PREFABRICATION IN FRANCE: MODELS AND CONSTRUCTION SYSTEMS

The know-how gathered up to the late 50s in the experimental yards sponsored by the *Ministère de la Reconstruction et de l'Urbanisme* (MRU) laid the foundations for the new public housing programmes developed by various bodies (HLM, Logecos) in the following ten years, based on *grands ensambles* policies [Fig. 1] and on heavy prefabrication [7]. Not only did this allow to reach the figure of 278,000 dwellings built by 1955, but even laid the foundations for the dizzy growth of the following years: 1,698,000 new units built in 1975, so as to peak to the 8,750,000 public and private buildings built during the *Trente glorieuses* [8]. As regards construction technologies and production structure, the heavy (*lourde*) or closed prefabrication was resorted to: it re-

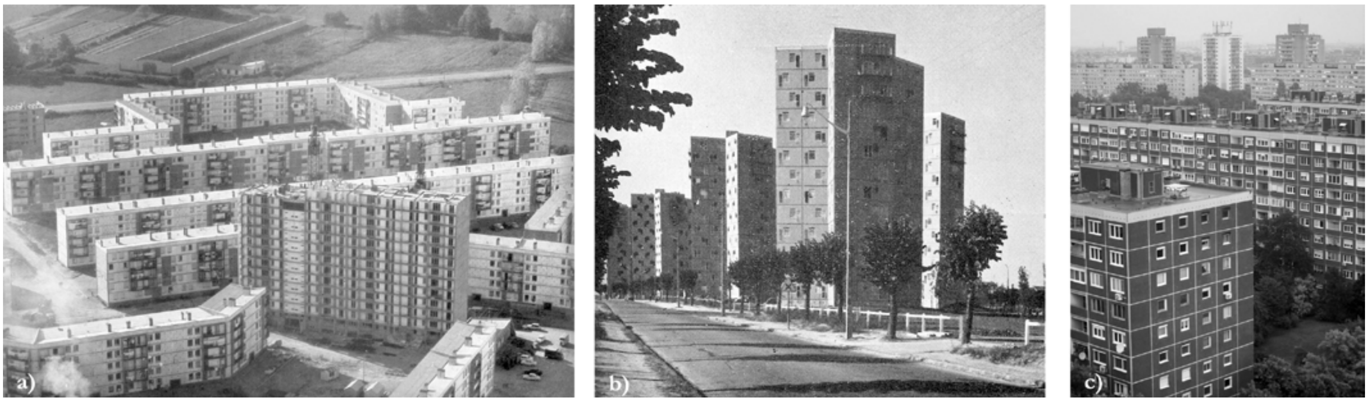


Fig. 1. *Heavy prefabrication and the new residential buildings in the 60s: Dreux (a), Savigny-sur-Orge (b) e Budapest (c).*

lied on reinforced-concrete- cast- in- formworks (*béton coulé*) panels, produced in specialised factories.

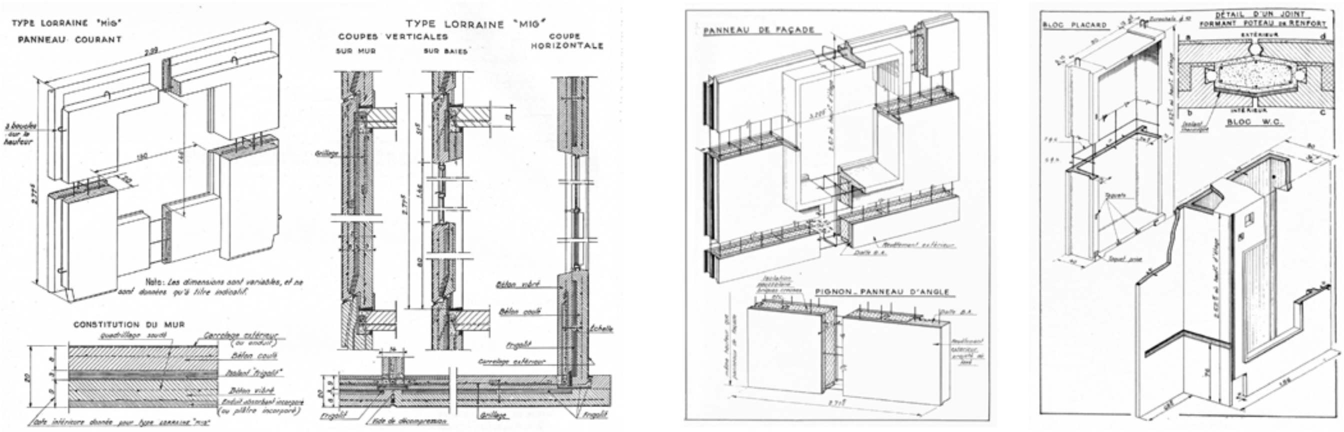
The main role in the MRU plans and in the 60s housing blocks development was played by the patents, which were the response of the French production system to industrialisation in the sector of construction. In the early 60s, various construction systems were introduced: they were mainly developed to realise high-rise buildings featuring weight-bearing front panels and both structural and partition walls, some of which derives from the first (Balency & Schul, Barets, Camus, Coignet) patents, and newly-conceived others (Costamagna, Estiot, Fiorio, Precoblin and Technove). In all instances, it was heavy or closed prefabrication: the reinforced concrete elements were industrially produced and were employed to obtain a complete high-rise building featuring weight-bearing both front and cross-sectional elements. There was a correspondence between room-sizes and front-panel-sizes, generally consisting in three layers (two weight-bearing external ones and an internal insulating one); the patents differed as far as the material employed for thermal insulation was concerned, i.e. cell-like material – such as Frigolit (expanded polystyrene) – [Fig. 2], or variously-sized, either brick or insulating-particles hollow elements [Fig. 2].

Among the systems belonging to the former type, the Camus patent enjoyed widespread success not only in the new French quarters but also in various European countries (Italy, Western Germany, Belgium, Great Britain and Austria) and non-European countries (Soviet Union, Algeria and Japan).

Filed in 1948 and developed until 1957, the Camus patent was essentially based on factory-produced large-size two-dimensional elements (such as walls and floors)

Patent	Year	Thickness (cm)	Stratigraphy (cm)	Materials
Balency & Schul	1959	21 + 1 (gypsum plaster)	10,5 + 3 + 7,5	r.c., insulating, r.c.
Camus – Lorraine	1962	19 + 1 (gypsum plaster)	8 + 4 + 7	r.c., insulating (Frigolit), r.c.
Camus – Serpec	1960	24	6 + 2 + 16	r.c., insulating (Frigolit), r.c.
Coignet	1961	25 cm	19 + 2 + 4	r.c., insulating (expanded polystyrene), r.c.
Barets	1956	23 + 2 (gypsum plaster)	5 + 18	r.c., hollow brick
Costamagna I	1956	25	3 + 18 + 4	r.c., hollow brick, r.c.
Costamagna II	1960	30	3 + 23 + 4	r.c., hollow brick, r.c.
Estiot	1958	22	3 + 2 + 17	r.c., hollow brick, r.c.
Fiorio	1963	20,5	2 + 17 + 1,5 cm	r.c., hollow brick, r.c.
Precoblin	1962	25 + 1 (gypsum plaster)	5 + 12 + 4 + 4 cm	r.c., hollow brick, empty, hollow brick

Fig. 2. *French main prefabrication systems in late 50s and 60s (layers are from exterior to interior).*



a) b)

Fig. 3. *Camus-Lorraine patent (a) and Balency & Schul patent (b).*

modulated according to the length of the room. The staple building that could be obtained resorting to the 60s-developed Camus-Lorraine and Camus-Serpec systems [Fig. 3a] consisted in 20-22 cm-thick front walls and 14 cm-thick weight-bearing cross-sectional walls on top of which full 13 cm-thick slabs and 7 cm-thick partitions were laid [9, 10].

The front panels featured two weight-bearing panels reinforced with 5 mm-thick metal rods and a Frigolit (expanded polystyrene) one; their edges were hinge-shaped, so as to house both the irons connecting one panel to the next and the insulating material making the seams tight [11]. Weight-bearing cross-sectional and partition panels consisted of full concrete slabs reinforced with one 5 mm-thick steel-rods mesh; their surfaces were smooth and could be either daubed with chalk-plaster or painted. Even in this case, the 10 mm-thick steel-rod connecting hooks protruded from the edges. The floors presented similar features; their upper edges were bevelled, so as to allow the curbs and the joints connecting the panels to be cast. The sanitary bloc featured a wall housing tubing and drain pipes as well as the brackets for kitchen appliances [9, 10].

The Camus system even provided for the panels to comply with finishing works: the window frames were embedded into the inside edge of the panels, in the same way as the metal door frames were encapsulated within the cast. The thin plastic laminate floors were glued directly onto the previously smoothed floor panels. The maximum weight of the elements reached 7t, so as to make their transport, handling and building-yard assembly easy [9, 10]. Through the 60s, the Camus system became the reference model for heavy prefabrication, even in Eastern bloc countries, where it triggered off various local developments [12].

The Balency & Schul system, on the other hand, belonged to the second – hollow elements – system., the patent, filed in 1950, envisaged 15-20 cm-thick Fibragloss insulating hollow panels, (Fibragloss is similar to Eraclit): their role being the weight-reducing and providing thermal insulation; the panels were placed in the moulds and cast concrete poured over them and over the window frames. Such panels could be employed by themselves in up to 3-4 storeys buildings, whereas in over 4 storeys buildings a reinforced-concrete framework was needed. Evaluations regarding production and the resistance of the panels themselves suggested that the hollow elements were to be substituted with insulating-material slabs (they were either 3-4 cm-thick expanded polystyrene or 6-8 cm-thick vermiculite-concrete slabs), as shown in the *agrément technique* issued by CSTB in 1956 (Fig. 3b) and by the addition to the previous patent applied for in 1966 [13, 14]. Vermiculite-concrete slabs, therefore, consisted of a 3 cm-thick external finish layer, a 5 cm-thick reinforced-concrete one, a 3-11 cm-thick insulating one, an internal 11 cm-thick weight-bearing reinforced-concrete one, an internal 1 cm-thick plaster one; this amounted to 23-31 cm-thick panels, depending on the thermal insulating performances required.

First in its kind, the Balency system introduced a weight-bearing vertical element named *bloc fonctionel porteur*, moulded in a seamless 5-10 cm-thick concrete block containing the landing general electric conduit risers, the meters, the conduit risers belonging to each flat, and the sanitary bloc. Resorting to such block allowed to build a two-dimensional uniform structure, so as to sizably reduce sanitary facilities fitting and connection times [10, 15].

Similarly to other prefabricated systems, the Balency system required resorting to weight-bearing cross-sectional walls that consisted of 8-15 cm-thick reinforced-concrete panels, and floors consisting in 13.5 cm-thick reinforced-concrete solid slabs, with the iron hooks of the reinforcing frame protruding so as to allow the slabs to be lifted and suitably connected together. As regards flat coverings, suitable 8 cm-thick reinforced-concrete slabs were produced; they had a 4 cm-thick expanded polystyrene insulating layer and were laid on the top ceiling. Though it did not enjoy the enormous commercial success of the Camus system, the Balency & Schuhl patent was reasonably popular in Europe: in Great Britain, it was introduced under licence from the patentees in 1964 and was resorted to in several housing blocs at Thamesmead, in Belgium and Ireland (1968), in Israel (1970) and in Italy (1964), where the MBM licensee company built several housing blocks in Milan.

4. DIGITISING THE REFURBISHMENT PROCESS

As explained in the previous paragraph, the preliminary study of prefabricated systems and their components has been essential in order to understand how houses built according to this technology perform adequately. The next stages of the analysis (i.e. surveying the "as-built" and project-related design of the buildings), with a view to their re-purposing and upgrading, will, in fact, start from the data gathered about the construction-related processes and assembly of their components. More specifically, as far as this particular sector of building stock is concerned, the analysis has been focused on the suitability of building information modelling (BIM) as the instrument of digital restitution regarding the "as-built" survey. Such an instrument allows the smart modelling of the single components of the building, providing descriptive information related to their behaviour as well as their geometric digital reproduction.

Family models tested	Results
Generic Metric Model	• Great modelling flexibility • Possible inclusion in the project without constraints • No data reading (thermal and structural performance) • Difficult association about the panels connections • Excellent results by exporting the drawings
Metric Curtain Wall panel	• Good modelling flexibility • No insertion possible in the project without constraints • Presence of a reference grid linked to the "curtain wall" • Problems in the union between multiple facades • Very difficult modelling about the panels connections • Panels identified as a single collaborating Curtain Wall: presence of energy performance, lacking of structural performance • Fair results about exporting the drawings
Generic Metric Model wall-based	• More complicated modelling directly as subtraction from a reference Wall • More difficult insertion of the project about the connection to the wall, but a good level of facade flexibility • Good solutions about the intersection of facades • Extreme ease in modelling the connections between panels • Panels identified as a single collaborating Wall: possibility to insert information both on energy and structural performances • Excellent drawings exporting

Fig. 4. *Summary table of the results obtained from the tests conducted on Revit family models.*

The Decreto Ministero delle Infrastrutture e dei Trasporti n. 560/01.12.2017 [16] makes the specific times and methods of the gradual digitisation of the buildings mandatory; hence, from 2025 onwards, public works contracts must resort to software structures. The survey undertaken proves quite topical: since most prefabricated housing blocks are owned by public authorities, as a consequence of the decree mentioned above, should they opt to upgrade their buildings, they would have to resort to BIM.

The researches undertaken have suggested it is necessary to define the guidelines for the future information management of prefabricated housing stock contained in BIM software since this typology of construction highlights some incompatibilities with present-day modelling standards [17]. Unlike other construction systems, prefabricated-panels buildings are managed and built relying on quite large (generally 280x360 cm) joined-together panels, rather than on brick and concrete.

Furthermore, the in situ panels are supposed to be the exact size as laid down in the datasheet according to which they have been projected and produced – which is a realistic surmise – taking the high level of industrialisation of prefabricated-buildings techniques into account. Each panel was developed with the precision borrowed from mechanical engineering (tolerance, modular coordination) and projected so as to be industrially reproduced (serial production). Besides, the panels were joined and installed following techniques that reduced assembly times. The available detailed records allow to trace the panels, thanks to careful information models thoroughly.

Front panels have been chosen as starting points, since not only do they (together with vertical and horizontal joints) represent the distinctive feature of the patent but also owing to the fact they are the most complex elements from a material, geometric and construction-related point of view.

The data gathered from surveying the original documents (patents and archival documents) prove to be an excellent launching pad from which to tackle digital restitution, leading to BIM prefabricated-elements mod-

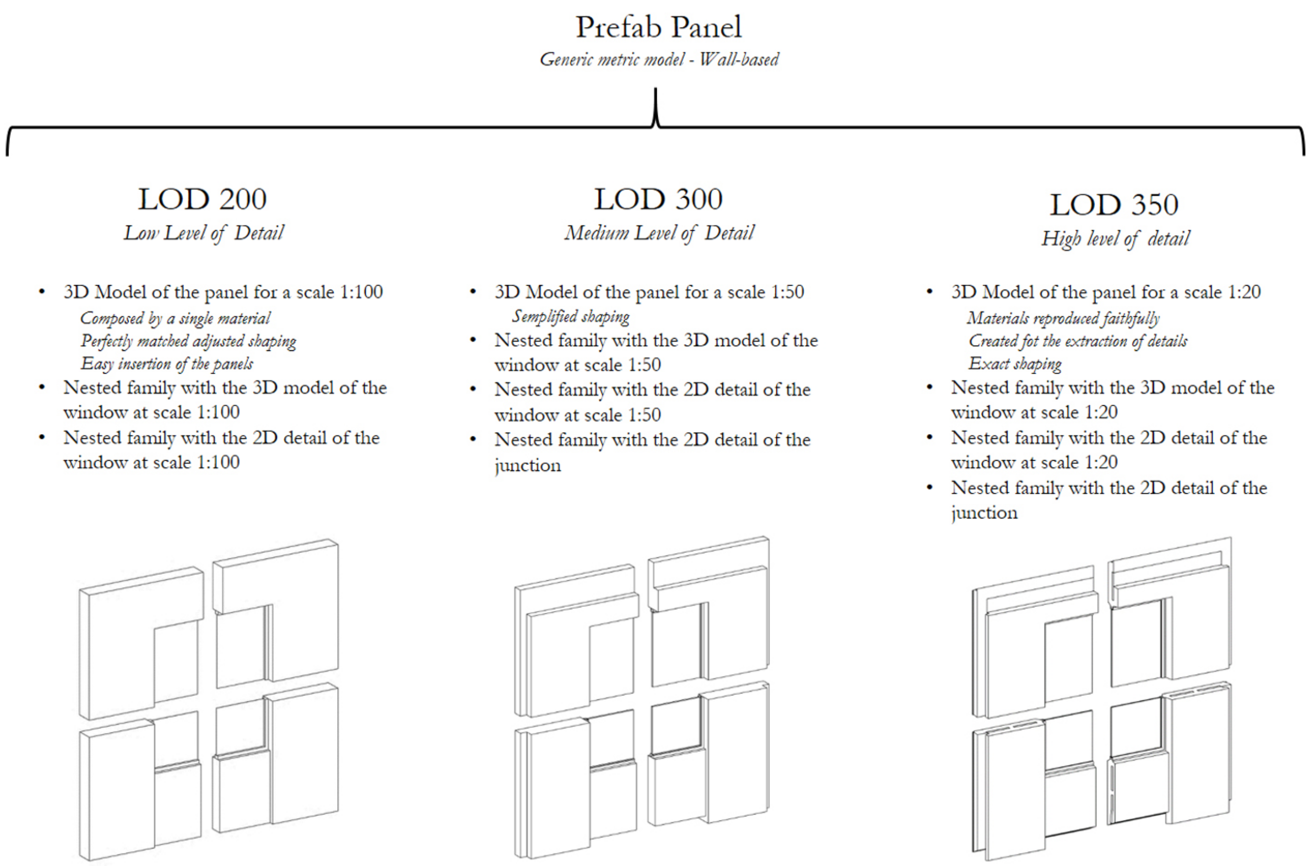


Fig. 5. *Components belonging to the generic metric family of the single prefabricated panel (Camus-Lorraine patent).*

elling in the best possible way. The main hindrance encountered is that each element is given a real function in the building; there is a specific key for the creation of single elements, though there is no equivalent option for the creation of a "prefabricated panel" and its joints. What is more, owing to the hierarchical logic of the programme, each class of elements must be subjected to system parameters that make it sharply different from all others: for example, a "window" or a "door" must necessarily be housed in a "wall"; a "beam" will be visualised in its structural, rather than architectural rendering.

The final objective has therefore been correctly modelling two-dimensional panels, which are the core elements of buildings, in order to obtain the architectural renderings necessary to assess the "as-built" conditions in an automated way [18]. Besides, thanks to resorting to BIM, the information, related to the different panels, has been connected together – for instance as regards the parameters of the materials, their state of decay, the residual performances of the various components – by means of instruments enacting simulations of the behaviour of the buildings in different upgrading scenarios.

To test the methodology proposed, Autodesk® Revit Architecture has been chosen as software. Each Revit-created element corresponds to a "family": some of these families can be customised, whereas others are defined as "system" families, that is to say, they can be modified only resorting to pre-set parameters.

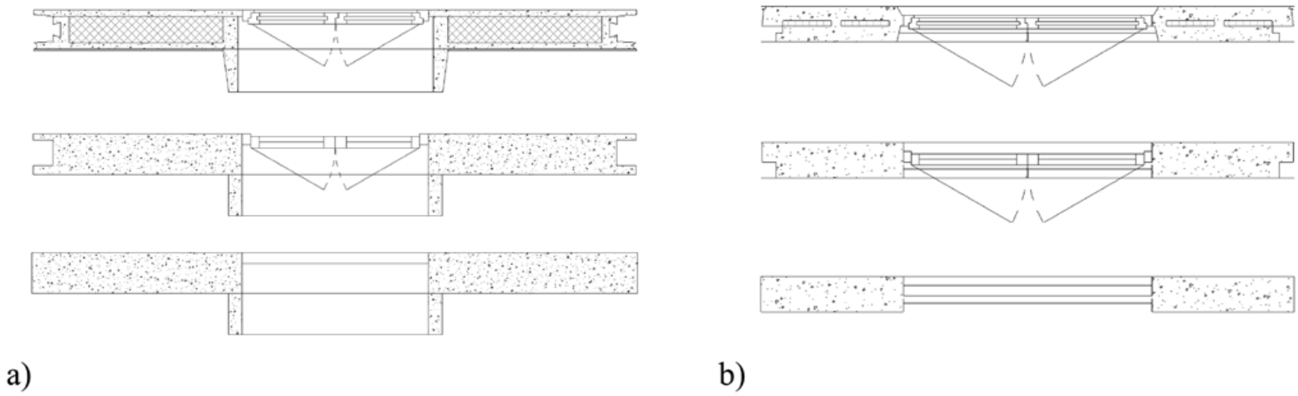


Fig. 6. *Example of the different plan LODs of the Balency & Schul (a) and Camus (b) systems.*

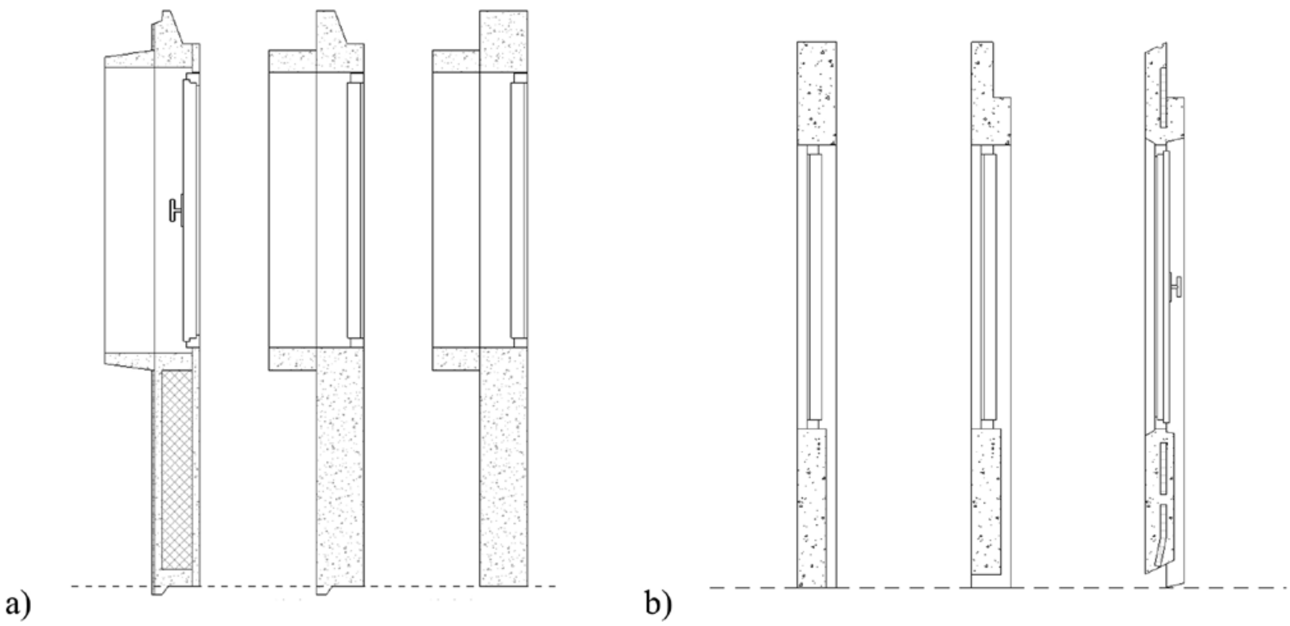


Fig. 7. *Example of the different section LODs of the Balency & Schul (a) and Camus (b) systems.*

Once a family has been created, it can be entered in the programme several times as an individual "instance" representing each different component of the model univocally: however, if the original family is modified, all the instances belonging to such family are updated automatically. Thanks to this operation logic, each single typology of panel can be modelled in the programme within a different family.

Later on, the kind of family with which to start modelling has been chosen. Several are the models of family within the software, none of which has the creation of a prefabricated panel as a defined function: various alternatives have therefore been tested in order to find the most suitable one for representing a panel with all its variables, which were identified in the phase of survey [Fig. 4].

Once the most suitable family was singled out (it was to correspond to the "Generic Metric Model wall-based"), we proceeded entering the information concerning its graphic visualisation; the correct combination of information allows to reproduce existing buildings correctly. This has been possible thanks to combining LOD (Level of Development) with the "Levels of Detail" present in the Editor of the Revit Families [19]. LOD provides references thanks to which the professionals of the AEC sector can assess at what level of clarity they are modelling: traditionally, the level of clarity varies in relation with the representative scale, though in 3D modelling such connection is not immediate [Fig. 5]. From the model it is in fact possible to select the scale automatically, so that the lines are made thicker or thinner, but can anyway be read; however, if the amount of the information needed by that particular scale is not entered, the model will prove insufficiently detailed. The LODs are defined by the AIA legislation published on BIM Forum with figures ranging from 100 to 500 [20]; the UNI 11337 Italian legislation, instead, modifies such scale with an A to G range. Such standard procedure allows to determine beforehand how specific the model has been chosen to be, so as not to make it redundant if the LOD is low (for instance when dealing with a general layout) or hardly readable if the LOD is high (for example when dealing with a construction detail). Thanks to the "Detail Levels" offered by Revit, three different modes of visualising the same object can be selected, so as to make such object more or less detailed according to the LOD agreed upon when entering the project [Fig. 6 and Fig. 7].

Three different levels of modelling panels have been created, corresponding to the three different Models of Detail, so as to obtain a more or less detailed panel, as required [Fig. 5].

The result obtained by means of modelling the various families provides a digital information tool that can be used to achieve an efficient replication methodology with reference to modelling. It will be required as far as possible "to mimic" the real assembly of a prefabricated building: after entering the series, under the heading "family", relying on the original "as-built" layouts, on a new Revit project file you proceed tracing the Walls and placing inside them – from bottom to top – each wall-or-floor panel. From the resulting model, thanks to the filter logic of the "Levels of Detail" and of the "Project Scale", the information implemented within the families can be accessed and managed; moreover, all graphic renderings of the "as-built" conditions in the various scales can be automatically extracted, avoiding redundant data.

5. CONCLUSIONS AND FUTURE DEVELOPMENTS

The research work has aimed to detect the perfect relation between the detailed study of the project and of its main components (that is to say front panels, in particular) and Revit modelling, resorting to the "families", testing the available ones, so as obtain a suitable 3D rendering of the panels, as well as the reading of all the materials and components by the programme [Fig. 8a and Fig. 8b].

As far as LOD (Level of Development) [19] is concerned, thanks to the many increasingly-detailed renderings of the same panel and thanks to setting (within the family) a visual variation of the scale, it has been possible to enter a suitable amount of information in the renderings. In this way, it is possible to resort to the families created in order to reproduce existing buildings, relying on the historical documents referring to "as-built" conditions, as well as on resorting to "Levels of Detail" in the main project with the aim of extracting the results. Following the above procedures, this research has evidenced the viability of BIM in the study of prefabricated housing, confirming the need to resort to a different methodological approach to upgrading, if compared to traditional framework-and-curtain-walls construction.

The next steps of the research will move forward towards gaining further insights into the material, geometric and construction-related features of prefabricated housing, as well as developing informatics rendering. As for the recent development, thanks to a comprehensive analysis, the research will focus on a building in its wholeness: i.e. its "as-built" local and global structural behaviour, the energy performances of external panels (theoretical thermal analysis), the modelling of the whole building; this will allow to assess its "as-built" global performances, and to create a reliable model, based on the available data.

As for the latter development, control logics (code and quality checking) will be created in order to check mistakes when setting the panels, as well as to monitor the compliance with technology-and-environment-related legislation; this will apply both to realising automatically-generated 3D positioning grids and to devising methods for the automated set up of the panels. Furthermore, it will be necessary to develop the interoperability and the coordination of the extracted information in order to develop models of structural and energy-performance-related analysis.

By taking the different production stance underlying prefabricated building into account, this research has prompted a different methodological approach to upgrade prefabricated buildings, based on analysing the industrialised construction systems and the buildings resulting from their application. The analysis of the construction systems from a geometric, construction-related and material point of view, together with the technical features (that is to say structural behaviour, energy performance, and construction-related peculiarities) of an "as-built" building, allows not only to identify its main shortcomings that may be emphasised by disrepair, but even to lay down a preliminary set of upgrading criteria that can be applied to industrialised buildings; in this way, working procedures will be better focused and, as a result, the economic sustainability of the project improved.

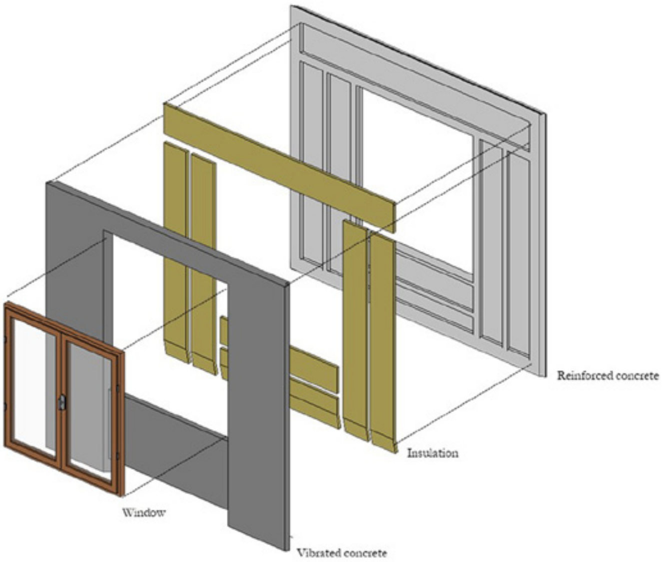


Fig. 8. *Axonometric exploded view of the Camus system panels made by Revit.*

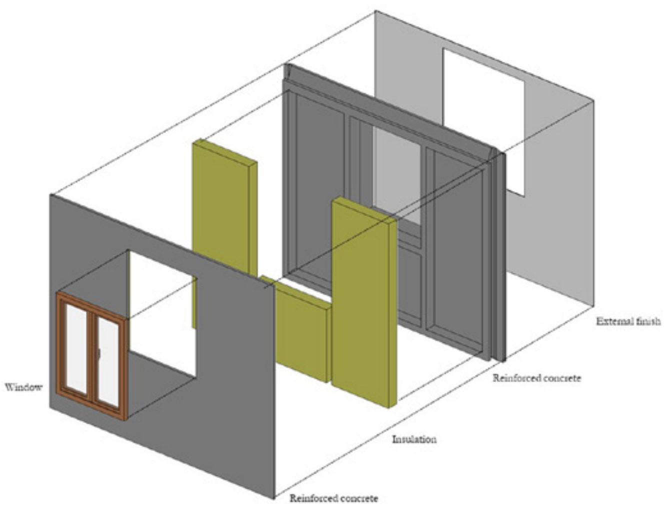


Fig. 9. *Axonometric exploded view of the Balency & Schul system panels made by Revit.*

6. REFERENCES

[1] European Union (2011). Roadmap to a Resource Efficient Europe. http://eur-lex.europa.eu/legal-content/IT/TXT/?uri=CELEX:52011DC0571. Accessed 15 April 2020

[2] Amasiu B et al (2011) Europ's buildings under microscope. A country-by-country review of the energy performance of buildings. Building Performance Institute Europe (BPIE), Bruxelles, pp 7–9

[3] The paper exposes the results of two project "Prefabricated Building Refurbishment. Individuazione di criteri e linee guida per il recupero funzionale e l'adeguamento strutturale dell'edilizia residenziale prefabbricata multipiano degli anni '60-'70"

[P.I. PhD. A. Bertolazzi, S.D. prof. Umberto Turrini], and the PhD tesi “Approcci progettuali relativi agli interventi di recupero e di ampliamento del patrimonio edilizio del Novecento secondo criteri di sostenibilità: Requisiti connotanti, linee guida progettuali e strumenti operativi di valutazione e gestione” [PhD candidate A. Maniero, Tutor, prof. U. Turrini], carried on within the ICEA Department (University of Padova)

[4] Antonucci R (2009) Restauro e recupero degli edifici a struttura muraria: analisi e interventi sul costruito storico, Maggioli, Rimini, pp 15–18

[5] Chemillier P (1977) Les techniques du bâtiment et leur avenir. Le Moniteur, Paris, pp 36–39

[6] Blachere G (1969) Savoir bâtir: habitabilité, durabilité, économie des bâtiments. Editions Eyrolles, Paris, pp 25–27

[7] Legoullon G (2013) Les grands chantiers de construction de logements au début des Trente Glorieuses en France, HAL. https://halshs.archives-ouvertes.fr/halshs-01202254. Accessed 15 April 2020

[8] Vayssière B (1988) Reconstruction, Déconstruction. Le Hard French ou l’architecture des Trente Glorieuses. Picard, Paris, pp 36–41

[9] Camus type Lorraine (1962). Cahiers du CSTB 58: 1–4

[10] Del Bufalo L (1965) La prefabbricazione edilizia in Francia. In: Prefabbricazione edilizia. AITEC, Roma, pp 70–77

[11] Oliveri MG (1968) Prefabbricazione o metaprogetto edilizio. Etas Kompass, Milano, pp 18–20

[12] Bertolazzi A, et al (2018) Socialismi prefabbricati: tipi edilizi e sistemi costruttivi per la residenza in unione sovietica e nei paesi dell’Europa orientale. Prospettive per il loro recupero. In: Cuboni F, Desogus G, Quaquero E (eds) Edilizia circolare. Colloqui.AT.e 2018, Cagliari 12-14 September 2018. Edicom Edizioni, Monfalcone (GO), pp 42–51

[13] French patent n°1510074, of 07/12/1966, INPI

[14] De Vita R (1965) Esame e classificazione dei sistemi di prefabbricazione. In: AA.VV., Industrializzazione dell’edilizia. Dedalo, Bari, pp 273–314

[15] Lembo F (1977), Le tecnologie di industrializzazione ed i sistemi di prefabbricazione utilizzati nell’edilizia civile francese. In: Industrializzazione dell’edilizia e prefabbricazione. AITEC, Roma, pp 167-184

[16] Presidenza del Consiglio dei Ministri, DM. 01 dicembre 2017, n. 560, “Modalità e i tempi di progressiva introduzione dei metodi e degli strumenti elettronici di modellazione per l’edilizia e le infrastrutture”

[17] ISO 16739:2013, “Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries”

[18] Maniero A (2018) L’uso del BIM in regime di interoperabilità interdisciplinare nello sviluppo degli elaborati progettuali [Tesi di Laurea]. Padova, Università degli Studi di Padova

[19] Castellano-Román M, Pinto-Puerto F (2019) Dimensions and Levels of Knowledge in Heritage Building Information Modelling, HBIM: The model of the Charterhouse of Jerez (Cádiz, Spain). Digital Applications, Archaeology and Cultural Heritage V. 14: 1–10

[20] BuildigSMART. 2019 Level of Development (LOD) Specification Part 1 & Commentary. For Building information Model and Datas. BimFORUM, 2019. https://bimforum.agc.org/wp-content/uploads/sites/27/2020/04/3.12.20-LOD-Spec-2019-Part-I-and-Guide-2019-04-29.pdf. Accessed 15 April 2020

TEMA
Technologies
Engineering
Materials
Architecture
e-ISSN 2421-4574
Vol. 6, No. 2 - (2020)

"LA FABRIL" RESISTENCIA'S INDUSTRIAL HERITAGE: RE-FUNCTIONAL CHANCE AND MANAGERIAL CHALLENGE

Daniel E. Vedoya, Claudia A. Pilar, Caterina Mele,
Paolo Piantanida

DOI: 10.30682/tema0602f

Highlights

The history of *Fabril Financiera* and industrialization in Resistencia. The relationship between people and industry settlements: outlining work, progress and social issues through chronicles and history. The difficult management of industrial heritage in a value growing context. The first project (Galdeano et al.) to save the Fabril district. The role of the people's feeling and actions. Public intervention and the present situation. The challenge of managing industrial heritage in a context of economic crisis. Lessons for the future.

Abstract

The *La Fabril Financiera* oil factory, founded by Juan Rossi in 1888, became a pioneer factory in the production of furfural oil. In 1919 it was acquired by the *Compañía General de Fósforos* and in 1920 by the *Compañía General Fabril Financiera*, becoming one of the most important industrial companies in the region. When "La Fabril" closed, the abandonment began: at the beginning of 2009, the official decision was made to demolish the complex to build a housing district, but a popular movement was organized to demand the preservation of the buildings, which motivated the Authorities to review their intentions and find a better solution to the need of the people of Chaco people.

Keywords

Industrial heritage, Housing districts, Urban regeneration, Building renewal.

Daniel E. Vedoya
FAU - Facultad de Arquitectura y Urbanismo, Universidad Nacional del Nordeste, Resistencia, Chaco (Argentina)

Claudia A. Pilar
FAU - Facultad de Arquitectura y Urbanismo, Universidad Nacional del Nordeste, Resistencia, Chaco (Argentina)

Caterina Mele
DISEG - Dipartimento di Ingegneria Strutturale, Edile e Geotecnica, Politecnico di Torino, Torino (Italy)

Paolo Piantanida
DISEG - Dipartimento di Ingegneria Strutturale, Edile e Geotecnica, Politecnico di Torino, Torino (Italy)

** Corresponding author:*
e-mail: paolo.piantanida@polito.it

1. THE INDUSTRIAL PAST OF THE CHACO PROVINCE (AR)

In Argentina, the interest in industrial heritage began in the 1980s, expressing itself mainly through local and inhomogeneous policies and initiatives. Because of its industrial past, Chaco has many buildings of historical and architectural interest: despite public intention to protect the cultural and material values of the abandoned industrial complexes, not much progress has yet been made in the identification and regulation of protected areas or even in the definition of standard intervention criteria to promote the conservation and enhancement of historical complexes. An emblematic case of this incoherence is the chimney of the *Forestal* factory, a large complex located in the city of Fontana, in the metropolitan area of the Grande Resistencia. The

Decree by Law No. 1130 of 2002 declared this building "the Province of Chaco's Cultural Heritage", but despite this, it risked being demolished in 2006: only strong intervention by the NGO *Memorias de Nuestro Pueblo* prevented the demolition [15].

Chaco's industrial heritage originated at the end of the 19th century when the main production activities shifted from agri-pastoral to industrial thanks to Argentine national policies that favoured the arrival of immigrants, many of them of Italian origin. French and German companies discovered the properties of tannin extracted from Quebracho wood for tanning leather and, at the end of the century, the 1895 census showed [18] that the settlements and cities with the highest demographic growth were those where the industrial plants had settled: Resistencia, Barranqueras, Colonia Benítez and Las Palmas, although at that time in history, Chaco's industry consisted mainly of distilleries and sugar mills. To give an idea, the capital invested by the companies of Las Palmas and Svea accounted for 86% of the total investments in the Chaco region, with their factories occupying an area of 29,619 square hectares. During the sugar cane harvest, the workforce required absorbed 20% of the active population. In the years that followed, Chaco's grew in line with the Argentine national ratios, tripling the number of industrial plants in just thirteen years (from 44 plants in 1895 to 144 in 1908). During that same period, the number of industrial workers rose to 3,171 in 1908, from 273 in 1895. The initial activities were gradually joined by oil production from different types of seeds, and the extraction of tannin from Quebracho. Industrialization was supported by massive inflows of foreign capital, mainly Belgian, French, German, English and American, and partly from the Buenos Aires region. It was also favoured by the extension of the railway line (Ferrocarril de la Provincia di Santa Fe) to the North East regions.

At the end of the First World War, market demand for Chaco's products changed: the main buyer was no longer England but the United States and Belgium, with a decrease in demand for tannins.

Chaco underwent another important expansion of its industry between 1930 and 1935. In 1935, the national census data indicated the presence in the region of 1.13% of the national industrial settlements, 1.35% of the employees and 1.66% of the installed motive power. The economic crisis of 1929 caused a worldwide collapse in export demand, so the industry market re-oriented itself towards domestic targets, where production was stimulated by the production of textiles such as cotton, food production and the oil industry, perhaps the most characteristic element of provincial production. The events of *La Fabril Financiera* began in this context.

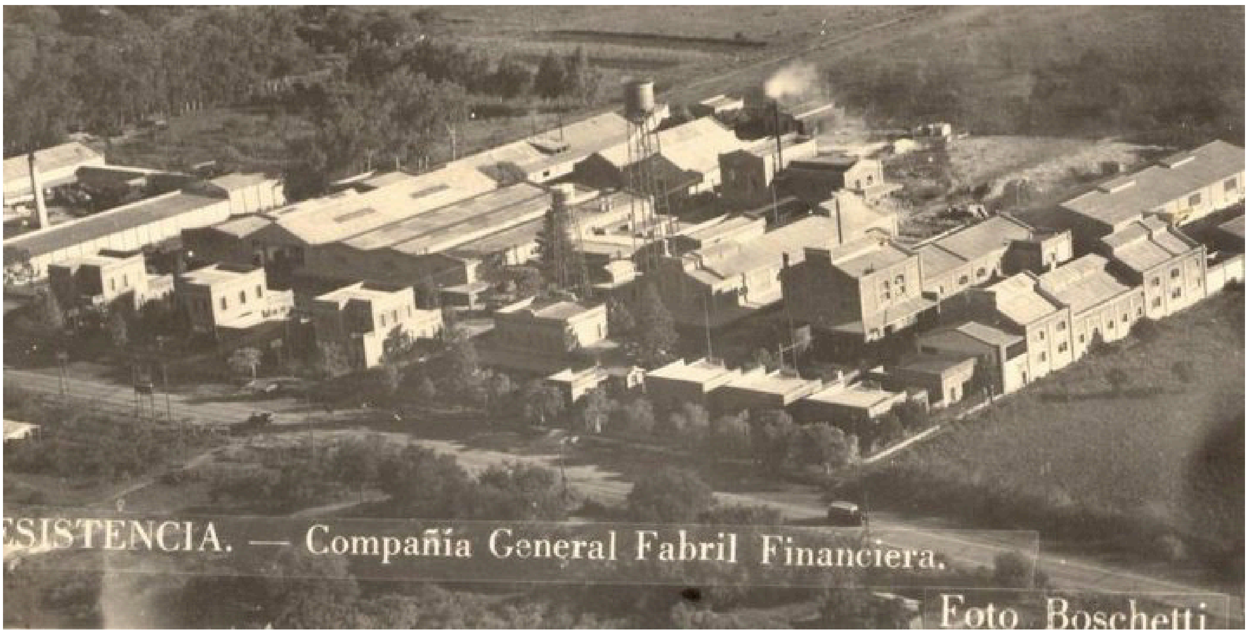


Fig. 1. *Compañía General Fabril Financiera, Resistencia. This aerial view goes back to the Forties. It was taken by the famous photographer Pablo Boschetti.*

2. OUTLINING THE "FABRIL FINANCIERA" HISTORY

At the beginning of the twentieth century, the major industrial activity in the city of Resistencia and the AMGR (Resistencia metropolitan area) was based on the transformation of local agricultural produce, as the Chaco province was and still is predominantly agricultural.

In fact, the leading industrial activities were linked to the transformation of agri-forestry products, particularly the extraction of tannin from the Quebracho and the production of various seed oils.

The industrial complex, now known as "La Fabril", was established in 1888, at the behest of Juan Rossi, an Italian immigrant who, just ten years after the foundation of Resistencia, planted a sawmill which was then converted to the processing of vegetable oils, pioneering the local production of castor, peanut and cotton oils.

In 1919, Compañía General de Fósforos purchased the land located in a site called "La Liguria", near the town of Barranqueras, to build a factory there. A year later, the President of Compañía General Fabril Financiera was the Italian Earl Antonio Devoto, assisted by Víctor Valdano as Head Engineer. They decided to purchase the Compañía General de Fósforos plant together with the land around it, transforming the unit into one of the most important manufacturing companies in the region. The area was ideal for the establishment of large-scale industrial activities, largely due to the efficiency of the communication routes, with the convenient railway network and the proximity of the Paraná River.

Fig. 2. *Mandiyu cottonseed oil, Thirties colour advertising.*

Seven years later, the General Manager Don Julio de Nicola, an eminent citizen of Resistencia, began building the large industrial complex that we see there today; in 1928, the San Fernando Oil Mill, formerly owned by Eugenio Varela, was added (Fig. 1): the seed oil produced was sold all over the country under the Mandiyu brand

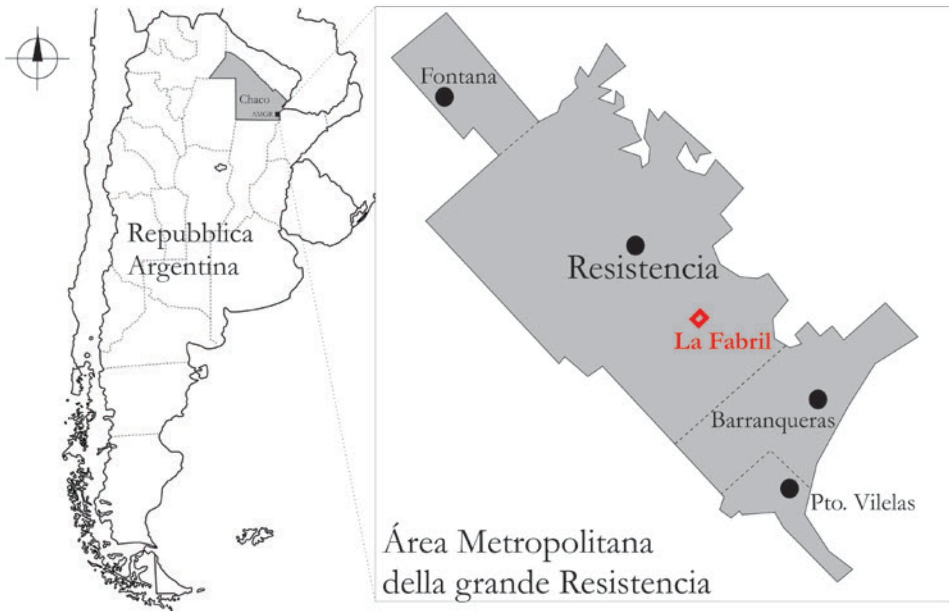


Fig. 3. *Left: map of Argentina Republic; right: the metropolitan area of the "Grande Resistencia" (AMGR). Resistencia is the capital of the Chaco Province, located in the northern part of Argentina (left); the complex of "La Fabril" is within the AMGR area, towards the city of Barranqueras (right).*

(vintage advertising in Fig. 2), and the operation continued for decades.

This industry gave work to thousands of Chaqueni for many years and was a true driver of progress and development. Today, however, the entire industrial area located between Resistencia and Barranqueras is almost completely abandoned, and the future looks vague. Together with other heritage sites closely related to the history and culture of Chaco, these former industrial areas are linked to the production chain and to railway development. They bear witness to the complex social processes that determined the human and economic aspects of local idiosyncrasy [13].

3. RESISTENCIA AND ITS METROPOLITAN AREA

La Fabril's location and its impact on the territorial system would be unexplainable without understanding the genesis and structure of the city of Resistencia.

Capital of the province of Chaco, in the North of the Argentine Republic, the city is the hub of the Metropolitan Area of Grande Resistencia (AMGR), which also comprises the municipalities of Barranqueras, Puerto Vilelas and Fontana, covering a total area of 33,578 hectares. Other places are related to its economy too, despite being separated by extensions of non-urbanized land: Puerto Tirol, Colonia Benítez and Margarita Belén. The location of the Chaco Province in the Argentine Republic and the AMGR, consisting of the four locations mentioned, is shown in Fig. 3: *La Fabril Financiera* is highlighted in red, towards Barranqueras (where the port is located), but still within the town area.

Resistencia is on the river Paraná floodplains, an area very rich in water which also comes from tributaries of the Paraná such as the Río Negro and the Riacho Arazá. The climate is warm without dry season, with an average annual temperature of 21 °C. Mean summer temperatures exceed 25 °C and the maximum temperature can be over 43 °C. In winter, average temperatures exceed 10 °C and the minimum temperatures are rarely below 0 °C. Average annual rainfall amounts to 1,300 mm: however, the Chaco province is characterized by the alternation of drought weeks, and heavy rains with floods and these morphological and climatic characteristics favour its predominantly agricultural and forestry vocation.

3.1. ORIGIN OF THE TOWN

Between October 1875 and March 1876, at the time of the presidency of Nicolás Avellaneda, a Commission was appointed to explore and assess places for a possible foundation of new settlements, including the area where the ancient mission of San Fernando del Río Negro had been active from about 1750 to 1774. At that time, an accident suggested the name for the new colony to be founded in this area. On February 6th, 1876, the Chief of the Chumpíes broke the agreement between the Aborigines and the Exploration Commission and attacked a village near the forest. The settlers and surveyors resisted the attacks nearby the home of Colonel J. M. Avalos: in memory of this, the new settlement took the name of "Resistencia".

Resistencia, together with Formosa, is one of the seven cities that were founded in implementation of the border areas defence policies that were implemented in 1878, at the end of the war with Paraguay and Brazil [11]. The birth of the city of Resistencia also came about due to the project to install a Government bridgehead in the Chaco territory and to encourage contact with the urban centres of Western Argentina [7].

What is now the town centre was originally the entire urban area and is based on the orthogonal territorial planning typical of the American colonies. Marked out by national surveyors in around 1882, the orthogonal grid was applied to the town territory without any consideration for the geological and hydrological characteristics of the area, rich in forests and lagoons. It was thought that the lagoons could and should be filled in and that all the geomorphological disadvantages could be overcome by dominating nature with the human intervention [11]. The consequences of this underestimation of the natural characteristics of the site resulted in numerous hydrogeological instabilities, in relation to the water regime and land drainage. Subsequently, all the lagoons were reclaimed and built upon them.

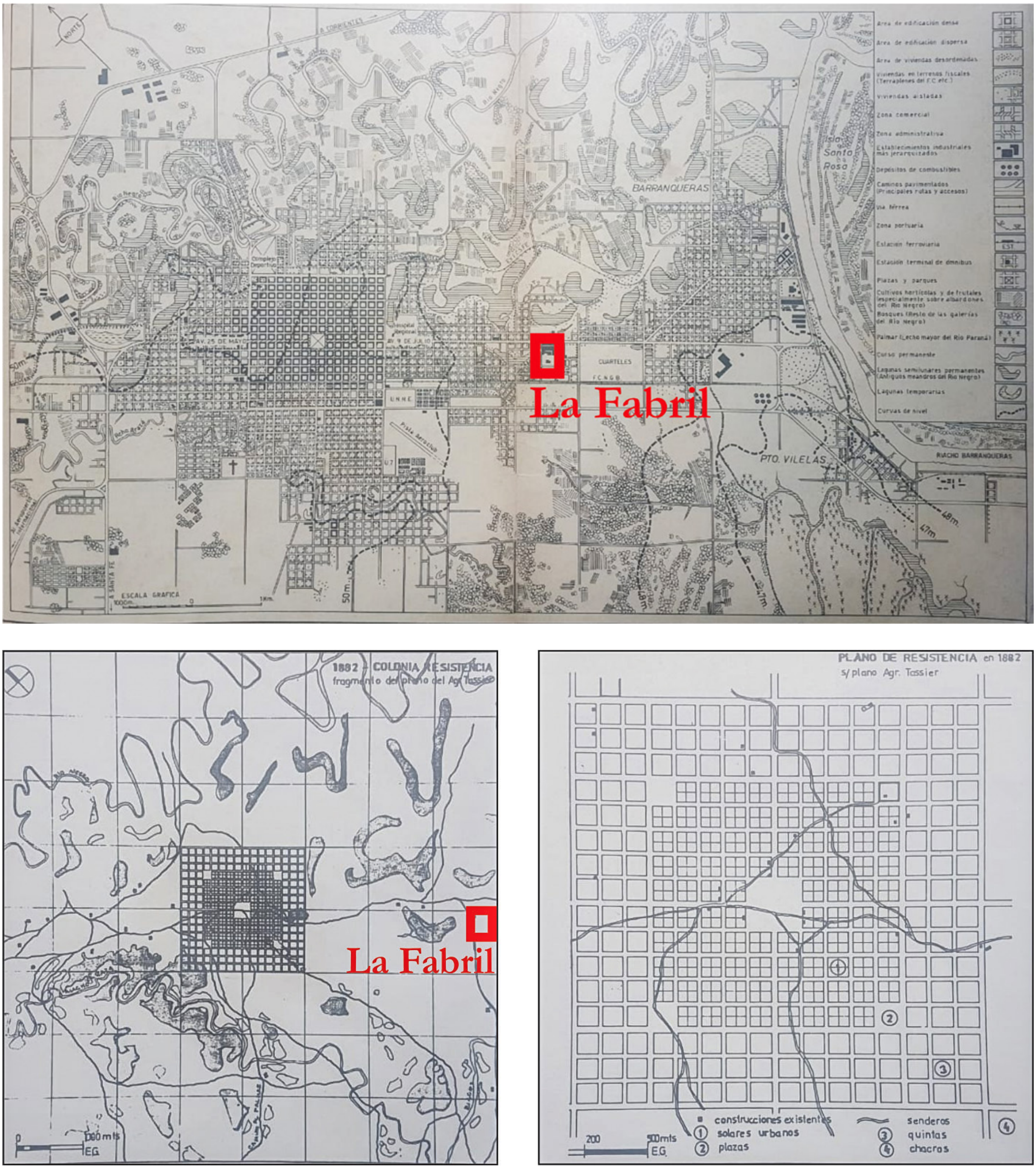


Fig. 4. *Resistencia, old town planning scheme (1882) [11]. Top left: Resistencia old town (1882) with the future location of "La Fabril" factory (in red) within AMGR; top right: old town scheme; bottom: map of the City of Resistencia (1978) and its conurbation of nearby locations [6]: it is obvious the huge growth of the city and the persistence of the regular planning scheme.*

The Immigration and Colonization Law of 1876 favoured the entry of various contingents of immigrants, one of which consisted of about 60 families from Udine (Italy). They landed in the port of San Fernando, above the Rio Negro, in 1878, intending to settle in the Colony of Resistencia. Afterwards, the city expansion was stimulated by the railways' construction and by initial industrialization financed by foreign capital, mostly from Europe. The original area, built up in square blocks within an orthogonal map of 400 ha of gross surface and 256 ha of the net land surface, soon began to grow: The rigorous and geometric layout of the city began to be altered by more disorganized and less organic forms.

Fig. 4 shows the map of Resistencia as it was in around 1882 in comparison with the city expansion in the conurbation area updated to 1978. The area occupied by La Fabril Financiera is also outlined in red. Its location on one of the city's main roads (Av. 9 de Julio) is of particular interest, as it strongly links the city of Resistencia with other towns in the Metropolitan Area such as Barranqueras and Puerto Videlas. This road also connects Resistencia to the neighbouring capital of the Province of Corrientes. The area's strategic location generates high speculation about the destination and use of the nearby allotments.

Considering the whole AMGR area, population growth has been constant since its foundation, as can be seen in the following data:

census	1895	1914	1947	1960	1970	1980	1991	2001	2010
population	2,187	8,387	64,700	108,287	142,848	220,104	292,287	359,590	385,726

Resistencia today

According to the 2010 socio-economic census, the city of Resistencia now has 290,723 residents within a province of 1.06 million inhabitants. In the last 40 years, the city has undergone dizzying population growth, tripling the number of people and requiring considerable urban expansion. This has been facilitated by the reticular orthogonal grid. The original blocks measuring 100×100 metres (which are part of a modular progression of 1000 × 1000 metres) have been extended into the surrounding rural areas. This implicitly suggested the continuation of the chessboard and has given rise to a sort of an "automatic" and unaware form of territorial planning that has tidily self-modulated the natural growth of the city. The only exception has been the progressively included lagoon areas, which still breaking away from the regular mesh of the city [5].

Currently, the urban area is divided between 55% residential and 30% public space (streets, squares, etc.), while industrial activities occupy less than 10% of the urban area, the bulk of manufacturing companies being located in the outlying areas of AMGR. The service industry (administrative and financial offices etc.) is located in the centre, occupying 2.74% of the territory, with commerce occupying around 1.65% and public gardens and green areas around 1.1% [19].

4. PROJECTS FOR "LA FABRIL" AND THE PRESENT SITUATION

When La Fabril ceased production, the whole complex underwent a period of abandonment and degradation. The four hectares of land are located in a central part of the metropolitan area, at number 2800 Av. 9 de Julio with buildings occupying a total of 10,000 square metres.

In 1974, Galdeano, Cayré, Salas, Escobar Pazos de Salas and Viain architects proposed one of the first plans to reuse the existing buildings for various purposes (residential, leisure and commercial) and the construction of new homes, all through a company named *Sucesión de Arturo Inocente*.

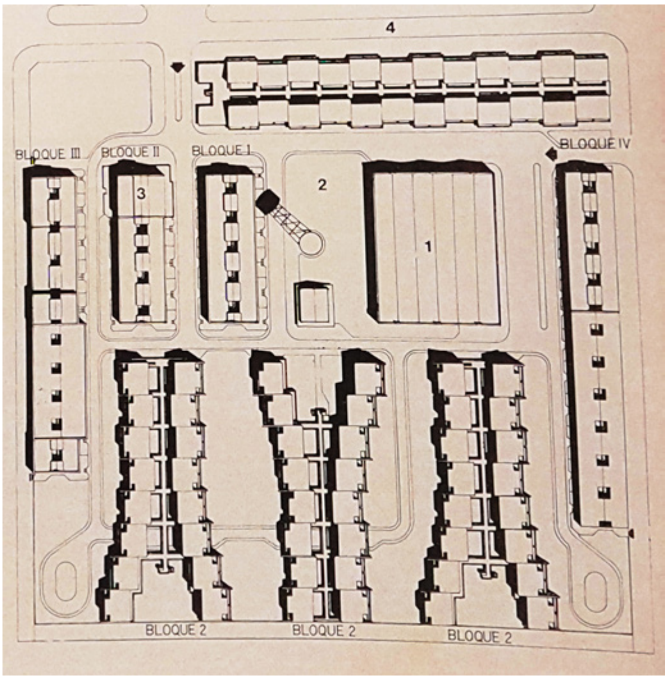


Fig. 5. *Galdeano, Cayré, Salas, Escobar Pazos de Salas and Viain architects: Masterplan (1974). The project contemplated the remodelling of four existing blocks for residential purposes. Part of Block II, originally used as a machine room, was allotted to a micro-cinema, a choperia, a restaurant with expansions and terraces, and entertainment venues.*

According to the authors' descriptive report "in an area of almost four hectares occupied by constructions once destined for industrial use, this housing complex is under construction. In addition to proposing new blocks of housing, it refurbishes part of the obsolete, semi-destroyed constructions, making the most of their possibilities, with the consequent economy. In this way, structures that were considered abandoned are revitalized and formally and functionally recovered" [9]. This project included 306 homes (based on the refurbishment of existing buildings and the construction of new ones), 14 commercial premises, a supply centre, children's playgrounds and service equipment. The design responds to respect for the built heritage and the proposal of a singular way of life, with internal semi-public streets strengthening the community idea of having their own place to live (Fig. 5).

The project contemplated the remodelling of four existing blocks for residential purposes. Part of Block II, originally used as a machine room, was allotted to a micro-cinema, a *choperia*, a restaurant with expansions and terraces, and entertainment venues. Unfortunately, this project never went ahead.

A supermarket (with warehouse and parking) was proposed for another of the existing warehouses, and the buildings located on Av. 9 de Julio were proposed for mixed-use: the ground floor for shops, chemist's, post-office, bank, office premises etc., with duplex housing on the first and second floors.

Other kinds of housing were proposed to the rear. They formally and functionally reinterpreted the existing typologies. They added innovative elements for public, semi-public and private use, with footbridges on the first floor [9], proposing the interesting idea of vehicle traffic with some *cul-de-sacs* and some passages under the buildings.

The remodelled houses were to be built in the existing blocks of the old factory, adapting smoothly to the variable modulation of the existing buildings. Access to the duplex homes was through their own garden, with the living room, dining room and kitchen on the lower floor. The upper floor housed the bedrooms and bathroom and a service patio favouring cross ventilation, beneficial in the hot-humid climate of the region (Fig. 6 and Fig. 9). The project was intended to integrate perfectly into the existing structure (the warehouse and shed walls are 45 and 60 cm thick), respecting the original openings. The only additional elements were wooden balconies on the upper floor [9].

Fig. 6. *Apartments integrated into the original factory (photo at the end of the works). All the openings have been respected; only wooden balconies have been added; in front of each entrance a small private garden enhances the sense of privacy.*

Fig. 7. *"La Fabril" Headquarters building (2018). Many buildings are in poor condition, as the main office building; they still keep in place original building details of great interest.*

Unfortunately, only a small part of the proposed renovations was built, due to uncertainties on the building site. The project was way ahead of its time in terms of the revaluation of industrial heritage, economic aspects, blended uses and the fair graduation between public, semi-public and private spaces. At the beginning of 2009, the competent urban bodies decided to demolish the existing buildings to build a residential neighbourhood. Faced with the imminent destruction of an important testimony of the city's historical and architectural industrial heritage, the people took action, demanding the conservation of the buildings. This social and cultural dynamic forced the Authorities to review the situation.

The events of La Fabril industrial site were studied by the Provincial Heritage Commission, which quickly acknowledged the complex as being "of significant historical and socio-economic value for the Chaco region". Following these determinations, the Chaco province promulgated the Provincial Law no. 6422/2009, declaring the former oil mill "Historical Cultural Heritage". This also fulfilled an old request from the "Barrio La Fabril Commission" which, back in 1998, had asked the Chaco Province Heritage Commission to preserve the architectural space full of historical and social significance.

Today, some of the sheds once used for processing inorganic products have been converted to residential use, flanked by craft activities, warehouses and commercial spaces (e.g. gyms). Those who live there have developed an idea of "belonging" to the site which forms a semi-public space due to its plant layout, with circulation routes all included within the limits of the neighbourhood and, consequently, with very limited traffic. The vestiges of its industrial past remain in the form of numerous sheds, now used mainly as warehouses. The place is full of historical significance and the unique characteristics: however, as can be seen in Fig. 7, many buildings of great architectural interest are still in poor condition.

Many pavilions have now been demolished, and others are in ruins. The railways' tracks are in the immediate vicinity of the La Fabril district, with other remains of old factories, military land and a lagoon area. However, what really characterizes the neighbourhood today and has changed its face is the residential settlement (Fig. 8). On the one hand, two pavilions of the old factory have been renovated and turned into homes and, on the other, new houses have been built in the southern part of the site, while Fig. 9 shows the renovation project to transform a disused shed into residences. From the 1974 project, the refurbishing of the old factory with transformation into housing (block I and part of block II) was carried out without the leisure activities proposed in the former machine room.

The 96 new houses built in 2015 do not respect the original idea, which was intended to give a unique and special character to the urban intervention. The project implemented by the Institute of Urban Development and Housing (IPDUV) in agreement with the mutual UPCP

Fig. 8. *Housings in the old factory, present state (2018). The sense of individual membership and ownership is clear by the different façade colours, while the new buildings for social housings (see Fig. 10 bottom right) show no sign of individuality.*

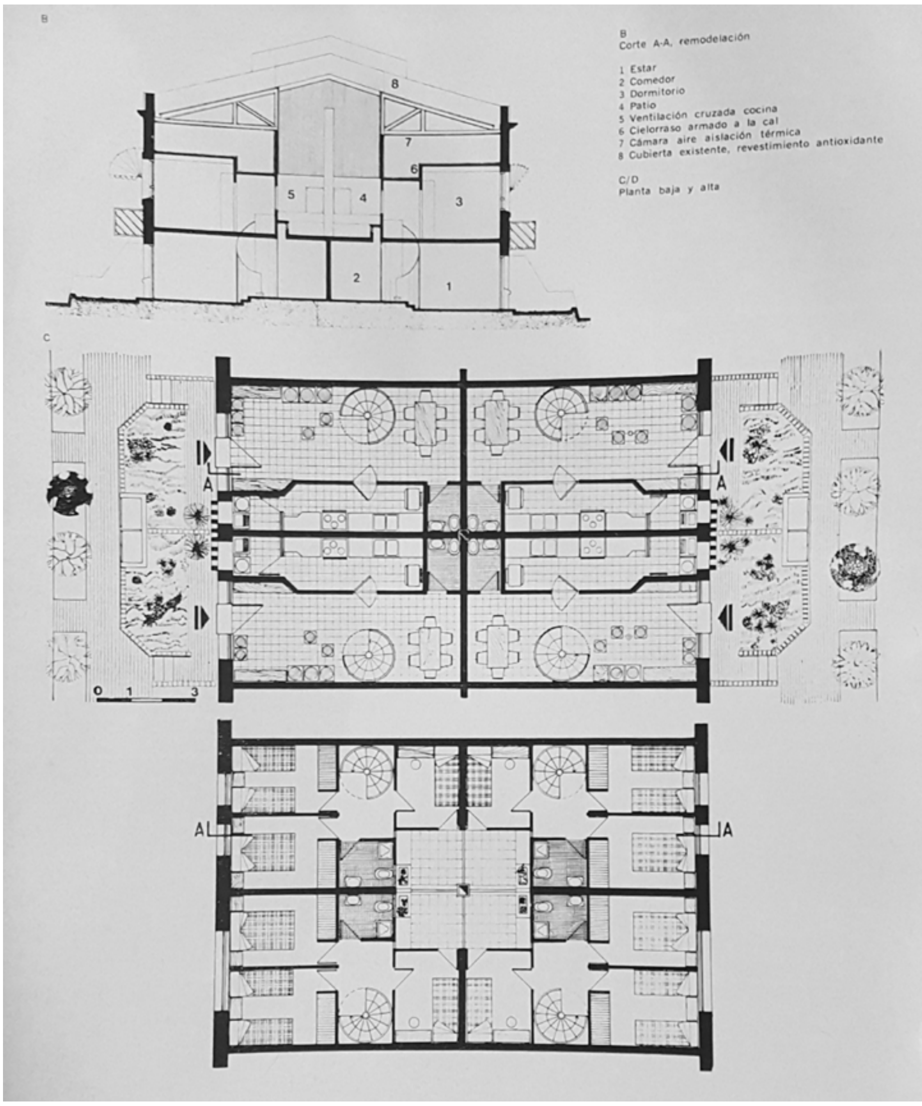


Fig. 9. *Plan for residential units in the old factory buildings (1974): cross-section, ground fl. and 1st fl. Plans. The project by Galdeano, Cayré, Salas, Escobar Pazos de Salas and Viain architects divided each module of the old factory into four duplex apartments with an upper patio for cross ventilation.*

Fig. 10. *Left: aerial view of "la Fabril" district; top right: old factory building converted to apartments (present situation); bottom right: standardized social housings (built 2015). The social housings replicated the typology designed by IPDUV & UPCP for the Chaco Province: unfortunately, the 1974 project was abandoned.*

(Personal Union of the Province) replicates the typology of social housing similar to other neighbourhoods in the city and province (Fig. 10). In this way, the opportunity to reinforce the idea of La Fabril as a unique and charming building complex in the city was missed.

Transforming a factory into a housing unit is a huge challenge, which arises from the typological differences between the two objects. However, as is usual for old industrial plants within the fabric of a city, it is one of the most attractive and necessary goals. The former suburbs are becoming the centre, and the industrial sites are currently fetching very high prices, due partly to their location on the main exit roads (Aguilar, 1998).

5. CONCLUSIONS: RE-FUNCTIONALIZE, OPPORTUNITY OR REALITY?

"Industrial architecture constitutes a wide field of knowledge and experience that can be viewed from a triple perspective. Firstly, as living architectural pieces that are subject to constant remodelling and reuse; secondly, as active agents of urban transformation and, thirdly, as a historical heritage in need of cataloguing, analysis and dissemination" [20].

The destruction of a large number of industrial buildings after the Second World War led to the emergence of movements to revalue industrial heritage [1].

La Fabril is a piece of Industrial Heritage in the city of Resistencia, thanks to which the idea of "place" as the context and population identity has been formed. As Montaner states [16] "[…] a place is defined by the qualities of things, elements, by historical, symbolic and environmental values". Individual experience is as important as a collective experience, and a "place" is more than a geographical location, more than just space, it is the tangible manifestation of human habitation [17]. Industrial archaeology aims to study material culture and the architectural, technical, social and anthropological aspects of activities related to the production, distribution and consumption of goods, the transformations of these activities over time and in socio-economic processes. The transition from the academic sphere to a broader one with strong social implications was accompanied by the increasingly widespread concept of industrial heritage [2], going so far as to directly involve the population, as the recent history of “La Fabril” has demonstrated.

As well as having an ethical and aesthetic dimension, the recovery of the industrial building heritage is an opportunity to apply a perspective of the circular economy [14] of matter and energy. This paradigm is based on environmental principles and savings (on the consumption of matter and energy and in terms of waste generation), which is of special interest to Argentina as it continues to experience an extensive and long-lasting economic crisis. Of undoubted interest is the revaluation of the passive energy of thick walls (45 and 60 cm), avoiding the generation of excessive demolition and construction waste (DCR) by reusing everything possible [10].

The reuse and recovery of historical industrial heritage is a proactive activity with a view to enhancing the history of a local area. It is currently desirable to reuse existing structures not only for reasons of environmental and social sustainability but also for economic issues, especially in contexts of particular socio-economic fragility, such as the city of Resistencia in Chaco. All these options are characteristic of the La Fabril site: a re-functionalization respectful of the characteristics of the buildings, with adequate conservation and restoration criteria, seems an excellent opportunity to highlight this “place” as evidence of a recent past that strengthens the historical identity of the city of Resistencia. Managing industrial heritage is a challenge that involves a complex network of technical, legal, cultural, architectural and social issues. This is why it is necessary to promote social support for this type of intervention, with the participation and involvement of local residents. In the absence of effective tools for this heritage rise and preservation, and clear guidelines for reuse and recovery, important evidence of the industrial past and identity of the place risk being erased.

6. REFERENCES

[1] Aguilar Civera I (1998) Arquitectura Industrial: concepto, método y fuentes. Museu d’Etnología,Valencia

[2] Álvarez-Areces MA (2008) Patrimonio industrial, un futuro para el pasado desde la visión europea. Apuntes 21(1): 6–25

[3] Pérez-Beveraggi R (2016) Las fábricas de aceites del Gran Resistencia. Diario Primera Línea 4738: 14

[4] Pérez-Beveraggi R (2018) Aquellas Fábricas del Gran Resistencia. Diario Norte, suplemento Chaqueña 2/9/2018: 7

[5] Borges JC, Scornik C (2001) Conflictos entre circulaciones y desarrollo potencial de la circulación peatonal en la Ciudad de Resistencia. UNNE Secretaría General de Ciencia y Técnica, Corrientes

[6] Bruniard E (1978) El Gran Chaco Argentino (ensayo de interpretación geográfica). Geografica 4

[7] Bruniard E (1979) El proceso histórico y los caracteres demográficos y socioeconómicos de la Ciudad de Resistencia. Folia Histórica del Nordeste 4

[8] Diario Chaco (2015) Capitanich entregó 24 departamentos en la ex Fabril. http://www.diariochaco.com/noticia/capitanich-entrego-24-departamentos-en-la-ex-fabril. Accessed 21 May 2020

[9] Galdeano E, Cayré A, Salas A, Escobar Pazos de Salas M, Viain V (1977) Primer Complejo Habitacional de Resistencia Chaco. Summa 114: 48–50

[10] Glinka M, Pilar C, Vedoya D (2013) Reducción del impacto ambiental a partir de estrategias de reciclaje y reutilización de residuos sólidos. Ediciones del ITDAHu, Corrientes

[11] Gutiérrez R (1983) El patrimonio Arquitectónico de los Argentinos, vol. 2: Nordeste, Corrientes, Misiones, Chaco, Formosa. Sociedad Central de Arquitectos and Instituto Argentino de Investigaciones en Historia de la Arquitectura y el Urbanismo, Buenos Aires

[12] Maskuppers (2015) La fabril - Resistencia (Chaco). https://youtu.be/Wqushvm8kKM. Accessed May 21st 2020

[13] Instituto de Cultura (2018) Patrimonio Material Chaco: los tesoros del Chaco. Gobierno del Pueblo, Resistencia

[14] Kirchherr J, Reike D, Hekkert M (2017) Conceptualizing the circular economy. Resources, Conservation & Recycling 127: 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

[15] Mariño MP (2019) Patrimonio industrial y memoria histórica como herramientas de reconversión urbana. Integración de la memoria en la planificación territorial de Fontana (Chaco). Paper presented at XXIII Congress ARQUISUR, Belo Horizonte, 2–4 august 2019

[16] Montaner JM (2002) Las Formas del Siglo XX. Gustavo Gili, Barcelona

[17] Norberg Schulz C (1979) Genius Loci: towards a Phenomenology of Architecture. Rizzoli International Publications, New York

[18] Rugier M, Sosa MJ, Balbiano RA (2019) Historia de la industria en la Provincia del Chaco 1884-2015. Hesquela de Gobierno de la Provincia del Chaco, Resistencia

[19] Scornik C (1998) Diagnóstico Urbano Expeditivo del Área Metropolitana del Gran Resistencia. SUPCE-SUCCE, Resistencia

[20] Sobrino Simal J (2010) Ver y hacer ver: modernidad y arquitectura industrial en España. Areas 29: 31–37

[21] Tartarini J (2014) Sobre el patrimonio industrial y otras cuestiones: escritos breves. Lazos de Agua Ediciones, Buenos Aires

H-BIM OBJECTS FOR MODERN STONE FACING GENESIS AND INFORMATIVE CONTENTS FOR THE SHELL OF THE STATION OF MESSINA

TEMA Technologies Engineering Materials Architecture
e-ISSN 2421-4574
Vol. 6, No. 2 - (2020)

Alessandra Cernaro

DOI: 10.30682/tema0602g

Highlights

To keep track of interventions carried out, or to be carried out, on a stone material facing of an existing building shell with historical-artistic features, an H-BIM (Heritage-Building Information Modelling) object of the construction element has been conceived to reach a more detailed characterisation of slabs both from a technical, specifying the properties of each one, and historical point of view, associating the Construction History phase in which the laying occurred. Thus, the consideration of a virtual and informative Abacus of Stones has been undertaken to make it an effective tool of knowledge and management for future actions.

Abstract

The revolution of the BIM methodology lies in the informative component attributable to digital entities, more challenging to define for the historical buildings due to the need to resort to documentary sources and diagnostic investigations instead of datasheets or virtual "pre-packaged" objects. In line with a research about the shell stone facing of the Station of Messina, a stylistic feature recurring in the public buildings of the 1930s-1940s, this study aims to conceive specific "H-BIM objects" so that they can represent new channels for collection and processing of data, in support of adequate Building Dossier and Maintenance Plan for cultural heritage.

Keywords

BIM (Building Information Modelling), Heritage-BIM Object, Stone facing, Station of Messina, Building Dossier.

Alessandra Cernaro
DE - Dipartimento di Ingegneria, Università degli Studi di Messina, Messina (Italy)

** Corresponding author: e-mail: acernaro@unime.it*

1. TOWARDS THE DEFINITION OF "H-BIM OBJECTS"

The scenario that emerges with the introduction of the BIM (Building Information Modelling/Model/Management) methodology requires a different approach to the design practise aimed at the digitalisation of the construction process. Greater control of the project and management of the building through its life cycle is possible thanks to the so-called "BIM objects", virtual entities that can increasingly emulate the reality, interact and interface with each other, promptly highlighting the onset of any interferences and anticipating the construction site ones [1, 2]. However, there is a difference in application between new designs and existing buildings, perhaps deliberately denounced by the adoption of the two acronyms BIM and H-BIM (Heritage-BIM), which are worthy of conceptual and operative considerations.

Although the methodology is not yet widespread and the regulations are still being defined, the benefits that can derive from the use of architectural, structural, plant engineering and infrastructural modelling through parametric objects – in technical language called *system/loadable/local families* – are more and more evident and interesting [3].

The data baggage related to them allows us to overcome the limits of CAD (Computer-Aided Design), and therefore of the simple vectorial restitution of the project, thanks to the possibility of associating "informative" and not just geometric features.

The effectiveness of the use of these objects is registering a new operative trend that induces the sector companies to provide the diffusion of the virtual equivalents of their technological solutions, with the attached *portfolio* of information, to simplify project processing.

If this is really advantageous when the aim is new construction, when recovering an existing building there is a higher degree of difficulty due to the lack of finding adequate objects on web sites of companies or in the online sharing platforms, without prior modification of the geometry and redefinition of the parameters that may lead to consider the creation from scratch more convenient.

The informative contents of the virtual models for existing buildings should be inferred by interpolating the data deriving from:

- *Historical-critical analysis*, to retrace the Construction History through documentary and bibliographic sources;
- *Survey of the state of affairs*, to acquire geometric-dimensional specificities and to find out the materials that were adopted;
- *Diagnostic investigations*, to determine the overall behaviour of the construction elements as well as to characterise the used materials from the physical-chemical point of view.

Hence, the information to be collected for an edifice, especially if it belongs to the historical-architectural heritage, is not only of the parametric type and exclusively related to its current state.

In these cases, it is necessary to protect technical and cultural reasons that require a critical recognition of the building past; the latter should be retraced by identifying the interventions, due to natural or anthropic events, which have occurred over time and may have produced variations of the original configuration defined during the design phase, often with the loss of peculiarities that should have been protected.

In addition to an analytical description of the technical characteristics, there is, therefore, the need to narrate the evolution or involution of a building or its parts, associating documentary evidence to the families adopted in the modelling and attempting to parameterise the "time" factor to define all properties that an "H-BIM object" should have.

Such purposes are not different from those of the Building Dossier, the operative tool that should be useful for multidisciplinary edifice knowledge and more conscious management, predisposing to adequate Maintenance Plans [4]. Thus, this study aims to test the contribution of the BIM methodology employing the "autarchic" stone envelope of the Station of Messina, which dates back to the 1930s and is subject over time to changes that have altered its technical and formal qualities.

2. THE "MODERN" STONE FACING OF THE STATION OF MESSINA: THE NECESSITY OF A NEW METHODOLOGICAL APPROACH FOR THE RECOVERY

The public buildings of many Italian cities built during the 1930s-40s were renowned due to the stone material cladding of the vertical, horizontal, external, and internal surfaces. It was assumed as the distinctive and essential feature of an architectural language that had to satisfy the purposes of modernisation and economic autarky of the Fascist Regime. Among these edifices, there is also the Central and Maritime Station of Messina (Fig. 1), designed by Angiolo Mazzoni, an engineer, at the end of the 1930s and formally characterised by smooth Alcamo Travertine slabs, also shaped according to curved profiles, and installed with aligned joints on a mortar substrate (Fig. 2) [5, 6].

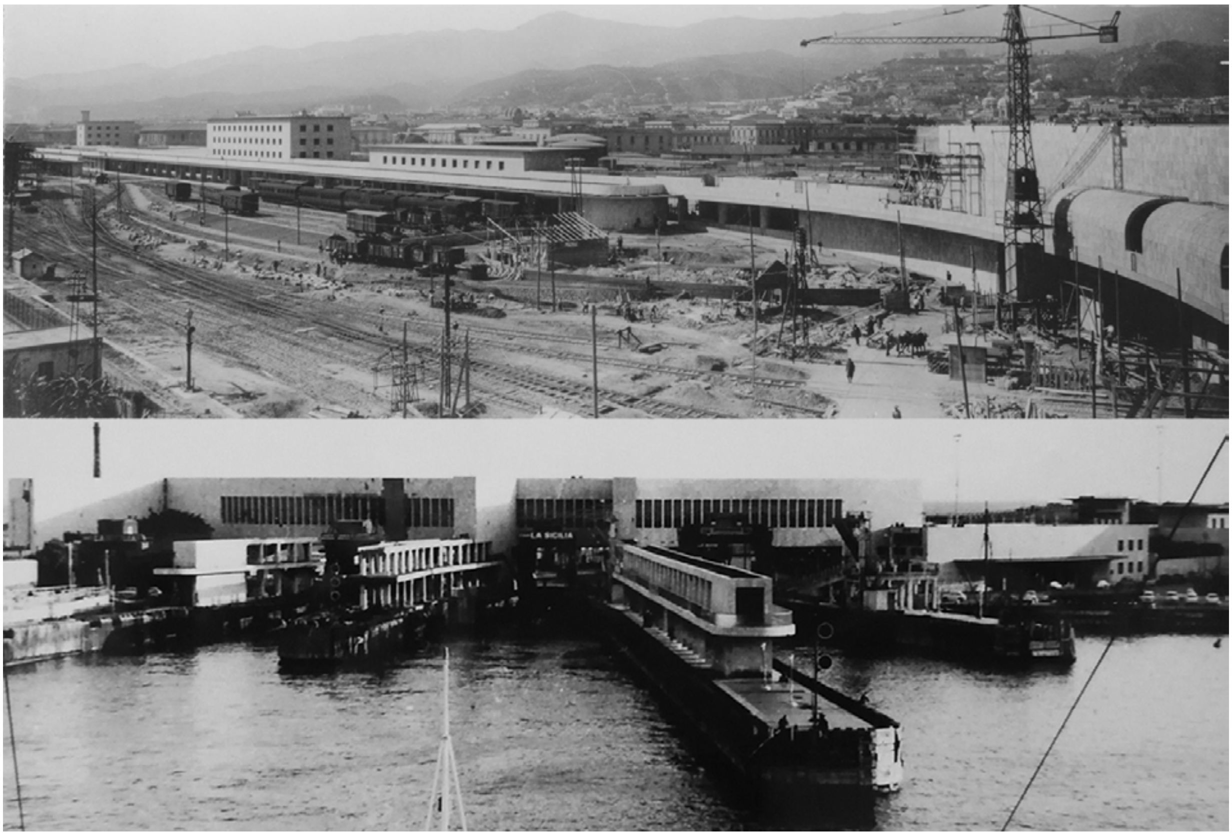


Fig. 1. *Central and Maritime Station of Messina with a view from the port area (MART, Fond "Angiolo Mazzoni", top; Collection of Laboratorio di Studi doCme 1908, down).*

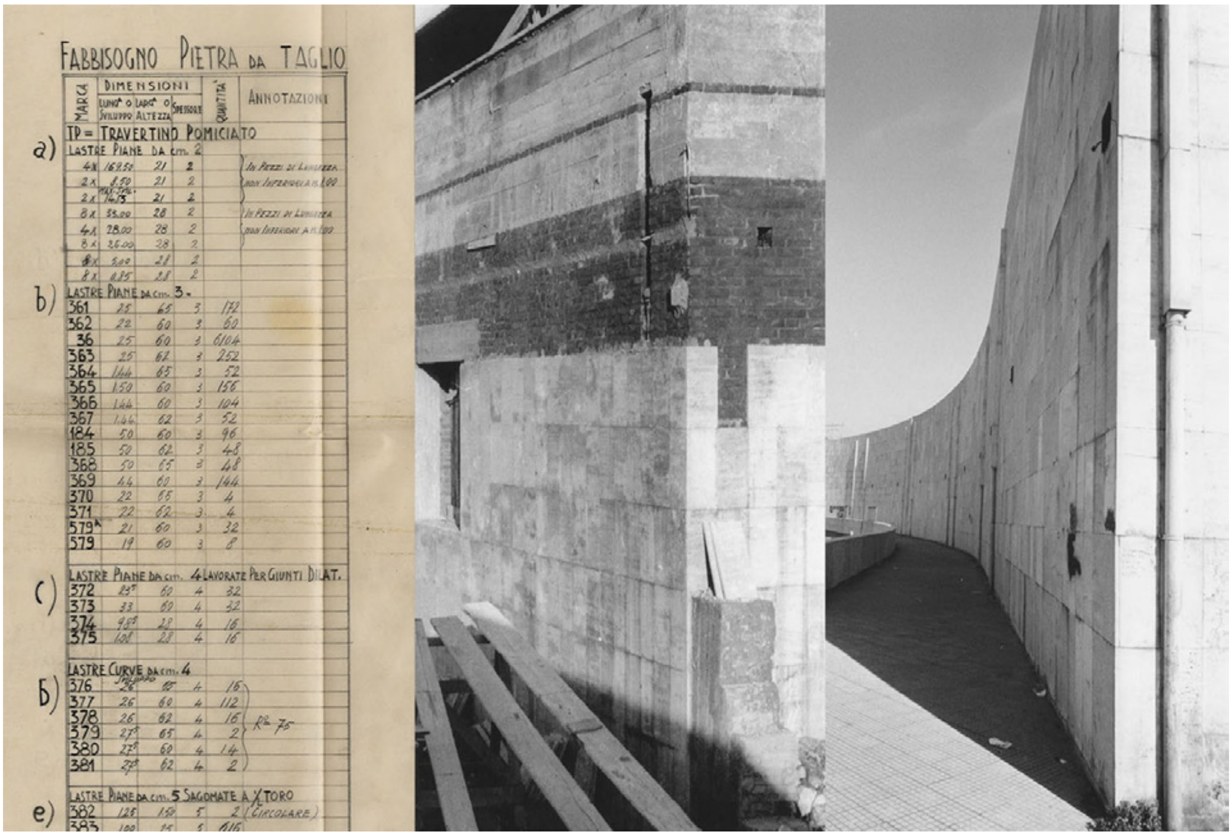


Fig. 2. *Specifications of the shell external facing of the Station of Messina (MART, Fond "Angiolo Mazzoni", left, centre; Collection of Laboratorio di Studi doCme 1908, right).*

Regardless of the ideological reasons, which with difficulty may be separated from "necessary" subjugations to the regime wills, the use of natural stone as a finish solution was real technological experimentation, in the desired opposition to its "artificial" version that in previous years had distinguished the majority of shells. The engineer Mazzoni, as a representative of the Work and Construction Service of the Ministry of Communications, included in his repertoire numerous designs of postal buildings and railway complexes in which he applied the stone facing [7, 8], firmly supporting the innovative application of this stylistic feature: "Stone, marble, granite have lost their weight, but have acquired the absolute beauty of their colour and their natural structure, of their soul. These load-bearing and architectural materials become decorative and protective. They make modern buildings beautiful and protect them from atmospheric agents. […] Our immediate predecessors […] resorted to artificial stone. Appearance, hypocrisy, democracy. I have these faults too. At that moment, I stammered, and I had not yet achieved that confidence, which now allows me to choose the good and the evil with certainty" [9].

Leaving behind the tectonic concept of the stone material led to the production of slabs of limited thickness and with complex shaping processes, that reproduce linear and curved profiles; besides, more often than not the trend was to reject the staggering joints because it was not necessary to even evoke correct laying criteria since the new "facing" function did not require it.

Similar to what Mazzoni did, many designers chose this lexicon that needed ability in architectural composition and technological knowledge. The planning had to be based on modularity criteria, deducible from the *Abacus of Stones* (where the geometric-dimensional and material characteristics of the modules were specified), and on the resolution of problems concerning the connection of slabs to the support, so the construction sites became the hotbed of innovation [10].

Therefore, there was a conspicuous architectural production that characterised the entire Italian territory, with examples in large or medium-sized cities, both of old establishment and born during the Fascist period. From Bolzano to Ragusa, from Rome to Littoria (nowadays Latina), there are numerous buildings with stone surfaces carried out by important people belonging to the Italian architecture field; in addition to Mazzoni, the generation of designers bonded by language analogies consists also of: Giuseppe Vaccaro for the *Palazzo delle Poste* in Naples (1928-35), Giuseppe Terragni for the *Casa del Fascio* of Como (1932-37), Adalberto Libera for the *Palazzo delle Poste* in Rome (1933-35), Mario Ridolfi for the one in Piazza Bologna (1933-35), Ernesto La Padula for the *Palazzo della Civiltà Italiana* (1937-43), Giuseppe Samonà together with Guido Viola for the *Casa del Fascio* of Messina (1940), and other architects and engineers that are part of a list that should be extended [10–12].

Hence, the stone shell of these buildings should be protected as technical culture evidence of the historical period in which they were conceived. However, this has not always been true for different reasons, specific to each case and context, which can only be deduced from a critical reading of Construction History.

Almost a century after its realisation, the cladding of the Central and Maritime Station of Messina presents conflicts in materials and composition that indict changes to the original configuration of the stone finish layer. The lack of documentary sources does not allow the reconstruction of the phases that characterised the past of the railway complex with an appropriate abundance of information, leaving doubts about dates, type, and extent of the interventions [13].

The damage caused by the bombardment in 1943 was certainly huge; less than a lustrum had passed since the end of the construction, dated March 31st 1940. For repairs, 10,000 m^2 of "travertine slabs and other marbles" were needed [14]. Although no distinction was made among stone elements necessary for vertical, horizontal, external and internal surfaces, thanks to the photographic documentation it is possible to assert that the more significant amount was used to restore the outer side of the envelope (Fig. 3). To comprehend the magnitude, bearing in mind the plan metric and altimetry dimensions of the railway complex – a frontage of about 600 m and an average height of 10 m – this quantity would correspond to the cladding of a façade with an extension of one kilometre.

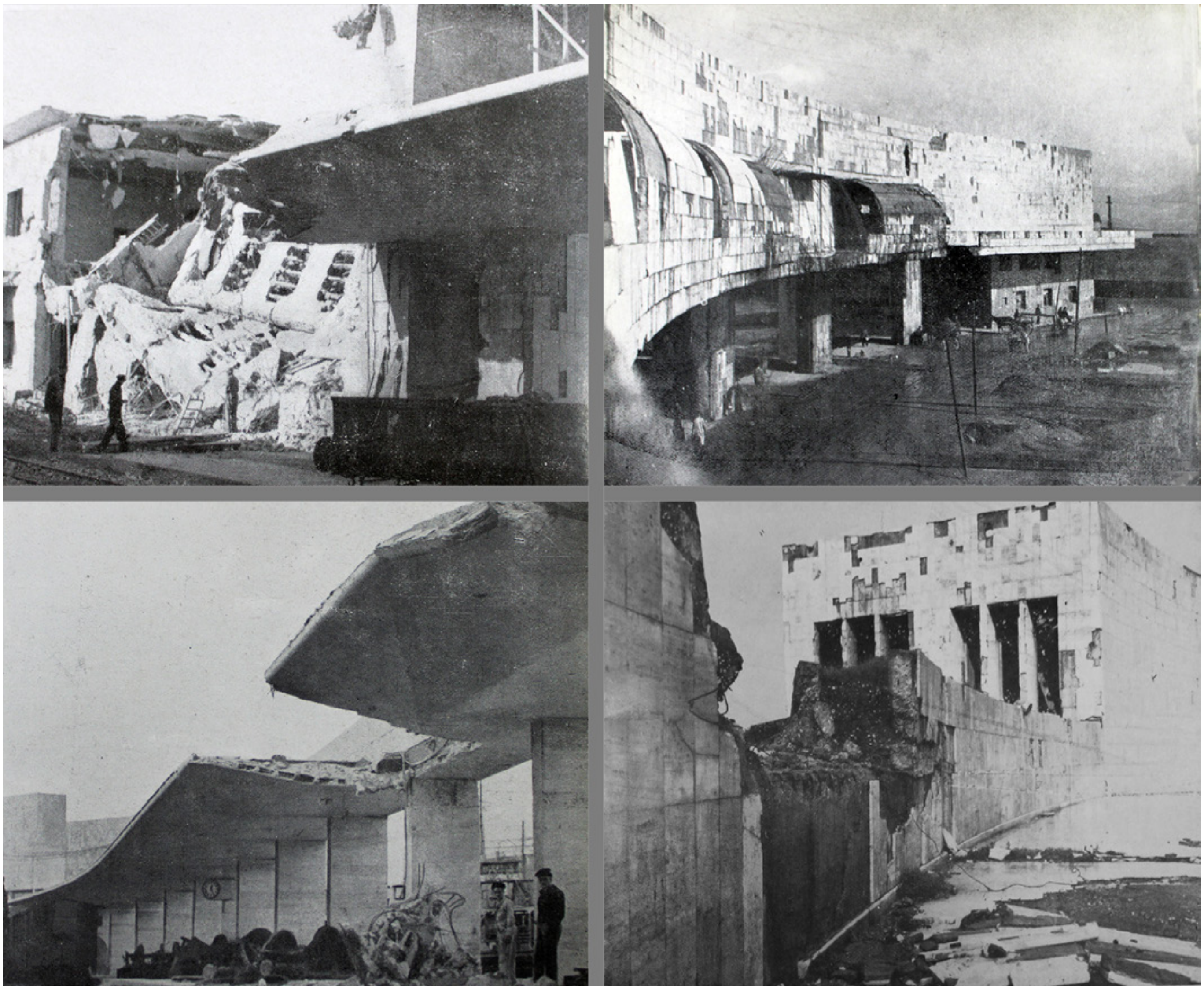


Fig. 3. *War damages to the covering of the Station of Messina (Scinia Collection) [14].*

There is only fragmentary evidence about subsequent interventions on the travertine slabs. However, from the comparison among the drawings of the original design, of the state of affairs in the 1980s, and of the extraordinary maintenance project carried out in 2001, some external and internal walls were added consequently to the modification of spaces; stone coverings were used to evoke the stylistic feature, often similar and using materials coming from different quarries. Even though it was easily deducible from a simple visual examination, it was discovered that specific actions on the finish layer with replacement or consolidation of slabs were performed over the years for natural and/or anthropic degradation amplified by the effects of vibrations generated by rail traffic. These works, which did not belong to maintenance programs, can neither be documentable nor datable.

This has unfortunately led to re-creations that are not always in line with the formal requirements defined by Mazzoni, perhaps succeeded by economic reasons and poor operative accuracy and supported by the absence of a protective restriction, which came only in 2002 and uniquely for the Maritime Station [15].

A portion of the Passenger Building of the Central Station is emblematic: originally it was a portico marked by pillars covered with travertine slabs; that over the time, due to its use, was closed proposing the "same" stone cladding of the existing shell; some slabs were replaced with others of a type of travertine dissimilar from that already employed, with different chromatic varieties

Fig. 4. *Front of the Passenger Building of the Central Station.*

and porosity degree that have influenced the aesthetic rendering; the choice of arranging the slabs with veins orthogonal to those of the pre-existing elements could instead be read as a sign of recognition of the intervention, since the same approach was also found in contemporary restoration solutions adopted in Messina for other buildings (Fig. 4).

Therefore, the failure to respect formal qualities can be attributed to an incorrect approach to maintenance, which is not often based on overall logics. The specific features of a building should be preserved, although it is not subject to protective restrictions, because they are an expression of cultural heritage. Greater control could be achieved if the interventions carried out over the time were traced to reach an accurate knowledge and management of the facing. In this sense, a result would be obtained with "H-BIM objects" to be considered as more complete data collection channels than traditional parametric objects. By processing the informative contents, it is possible not only to estimate the physical, mechanical, chemical and thermo-hygrometric behaviour but also to conduct assessments to guarantee the protection of technical-cultural reasons, to safeguard memory and function.

3. AN H-BIM OBJECT FOR A SHELL WITH STONE FACING: FROM THE SPECIFICATIONS OF THE MODEL TO THE "TIME" FACTOR

The portfolio of an H-BIM object should include the contents necessary to reconstruct the evolution or involution regarding the considered technical element. However, this presumes the creation of a model that is able to incorporate, return and process them and in which parameterising the "time" factor, providing the virtual entity also "archival" purposes to accept past, present, and future information of the real system it represents.

In the case of a shell with a stone material facing, the protection of material and technological specificities could be more effective if a precise knowledge of its elements and of the interventions carried out over the years was reached. Therefore, the related H-BIM objects should be modelled to satisfy these needs and originate more aware and proper maintenance actions.

The first step in defining a possible methodological approach has concerned the creation of the vertical closure model with external finish in travertine slabs of the Station of Messina, identified as an “excerpt” on which to test the course of the research, using software of BIM authoring for architectural modelling of the Autodesk® Revit type, currently in use, not excluding subsequent checks with other programs. In the BIM language, the vertical closure, as a technological unit, falls within the *system families*. Starting from the most similar type among the “basic walls” provided by the software, a modification has been made to reproduce the desired stratigraphy. For the variability of the geometric-dimensional characteristics of the construction elements deduced by the original design documents, a study configuration has been undertaken having:

- an external finish in flat slabs of Alcamo Travertine of 3 cm thickness;
- a layer of mortar of 2 cm;
- a resistant part in masonry or reinforced concrete of 30 cm;
- an internal plaster finish of 3 cm (so defined for simplicity of dissertation, although the adoption of stone slabs may also be observed for these surfaces).

Nevertheless, a limit has been found during the definition of the multifunctional package: each layer can be represented and described, but it is not possible to differentiate the properties within it. This is particularly restrictive for a stone material facing because, although it is allowed to define its thickness and give information on the adopted stone variety, the slabs can be reproduced only graphically attributing a pattern to show their step in the horizontal section of the layer (Fig. 5). Such configuration does not satisfy the expected results of the research that aims to create a model through which a more detailed characterisation of this finish type should be achieved.

Therefore, the modelling of a virtual “data container” has had to be conceived from scratch, because suitable solutions have not even been found in the online sharing platforms of parametric virtual objects that were consulted [16]. This confirms that for existing buildings it is not always possible to benefit from one of the advantages advertised by users of BIM software that is the possibility of employing already “pre-packaged” informative objects, provided by companies that develop computer programs or by those that design technological solutions.

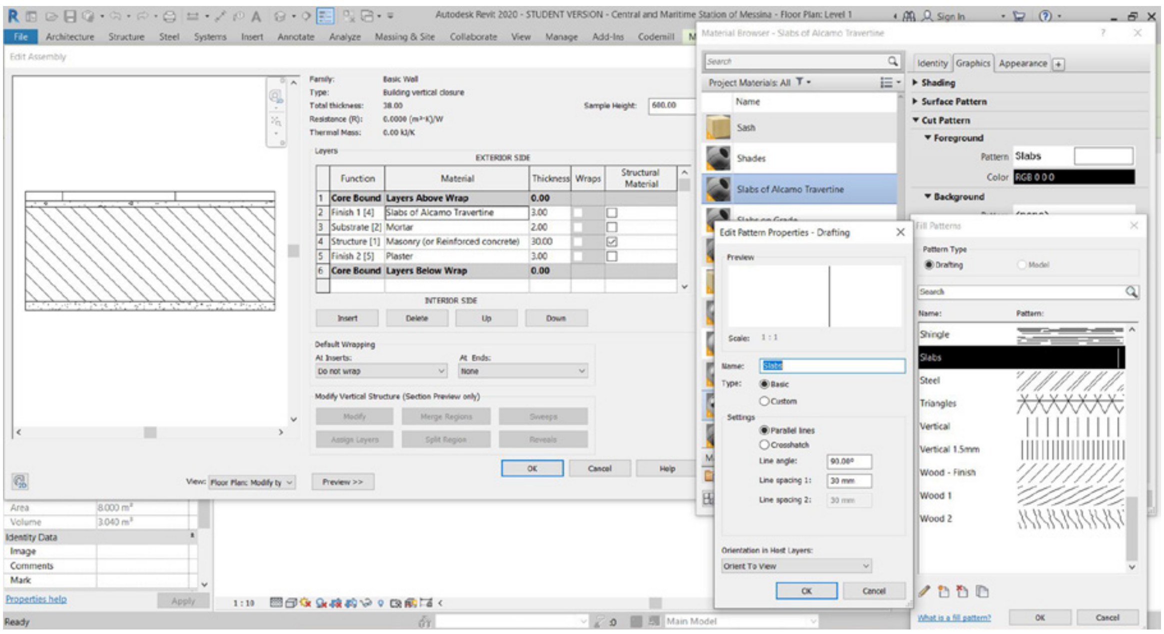


Fig. 5. *Stratigraphy of the vertical closure obtained by modifying the “basic wall” more similar to that of the Station of Messina in which the facing slabs can be represented only with a pattern.*

Conversely, a more functional model of a wall with a stone coating could be obtained considering it as the composition of two families: a *system* one, to reproduce its stratigraphy except for the external finish layer, and others *loadable*, one for each type of slab.

Indeed, the original design drawings of the Station of Messina's envelope show that slabs with different morphology were conceived according to the linear or curved profiles of the construction elements to be covered. Therefore, some have a rectangular cross-section and others were shaped so that the face of the stone element follows the concavity or convexity of the non-linear portions of the wall to increase, in the absence of metal fastening devices, the surface of adherence slab/mortar.

By considering for simplicity a stone element with a rectangular section, the *loadable* family has been created starting from the *metric generic model wall based*, recommended if it is necessary to reproduce components to be inserted within a wall or on its external or internal surfaces.

Although the front part of the Station of Messina has joints of about 2-3 mm filled with mortar, and therefore their graphic representation could be neglected, the BIM object has been designed to be applied even if they have larger dimensions.

To facilitate the process, it has been considered proper to create inside the basic wall of the *loadable family* – having non-specific stratigraphy, materials, and thicknesses – a slot, obtained using a *void extrusion*, in which to insert the modelled slab as a *solid extrusion*. The parallelepiped has been constrained to six reference planes containing its faces, whose relative distances have been parameterised to manage, through the *family parameters*, the dimensions of the virtual object, namely width, height, and thickness (Fig. 6).

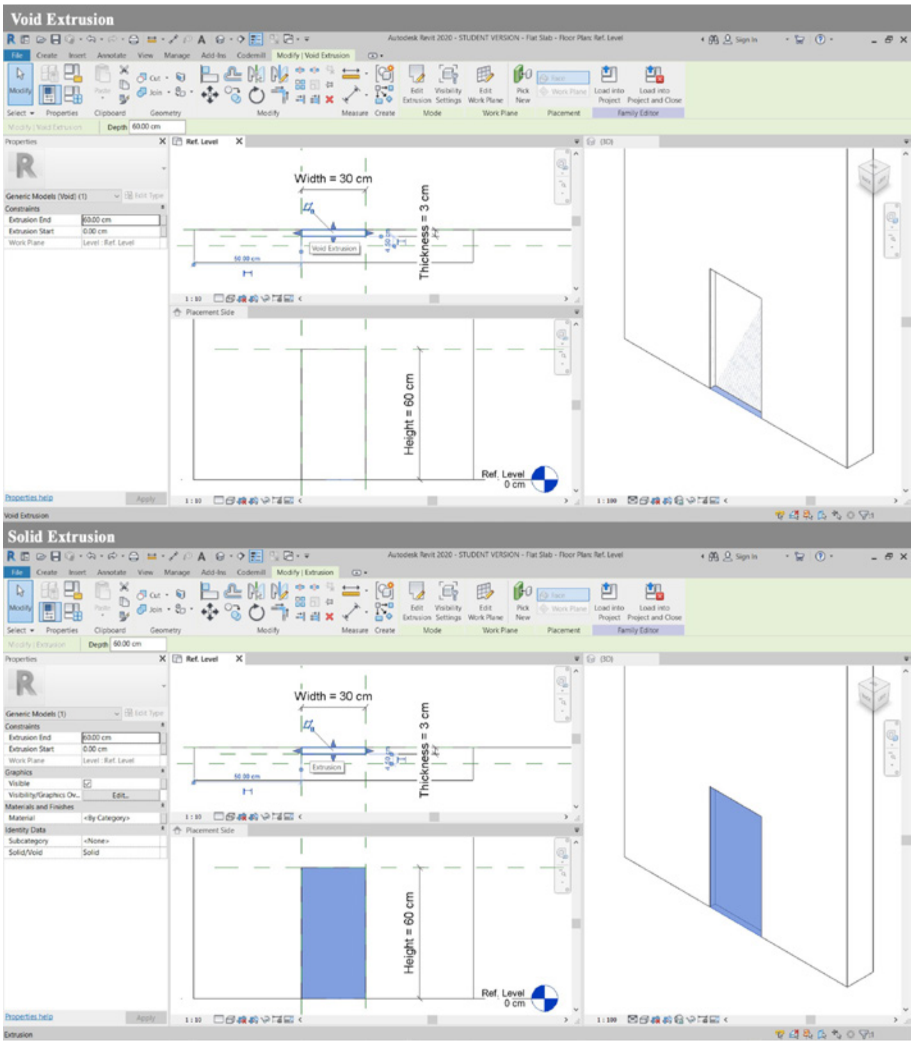


Fig. 6. *Flat slab, a "Loadable Family" constituted by a void extrusion and a solid one.*

Hence, the BIM object becomes the virtual minimum unit of the cladding that, loaded in the *project file*, can be modified "as a type", to permit the dimensional variations of the rectangular cross-section slabs, and "as an instance", to differentiate the properties of each element that can be changed over the time compared to the original homogeneous configuration (for example a different variety of travertine adopted in case of replacement of damaged or degraded stone elements) (Fig. 7).

The procedure, replicated for the other two types of slabs with concave and convex faces, will allow the re-creation in the BIM software of the *Abacus of Stones*, present in the drawings of the executive project, in which each type of slab is identified through a code called "marca" (Fig. 8).

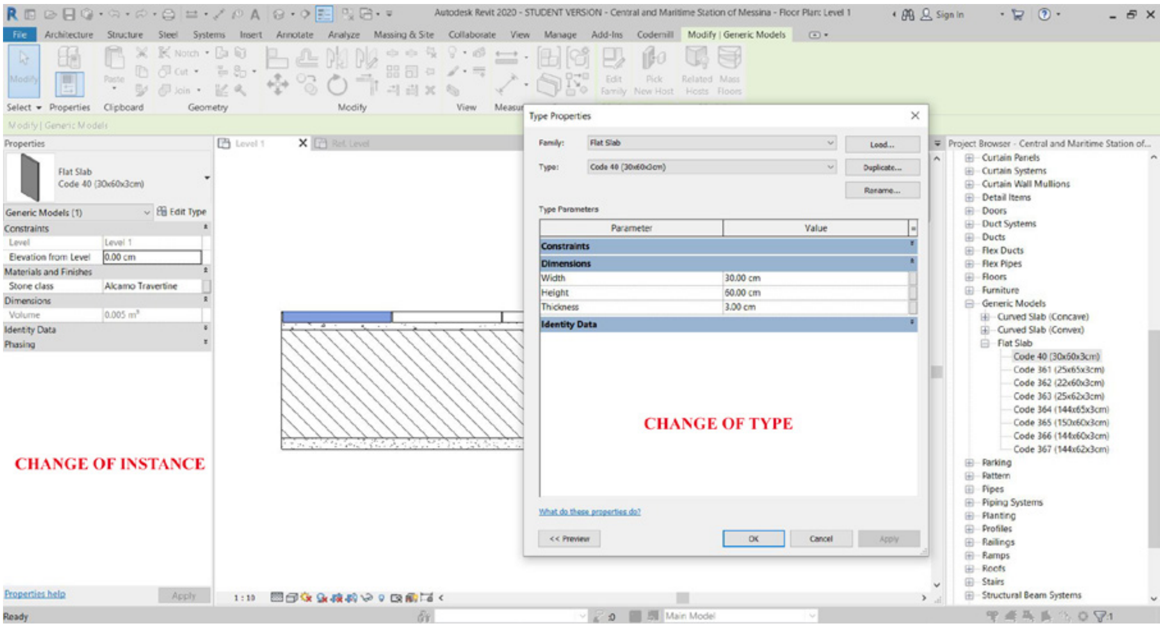


Fig. 7. *The Flat Slab in the project file, changes "of type" and "of instance".*

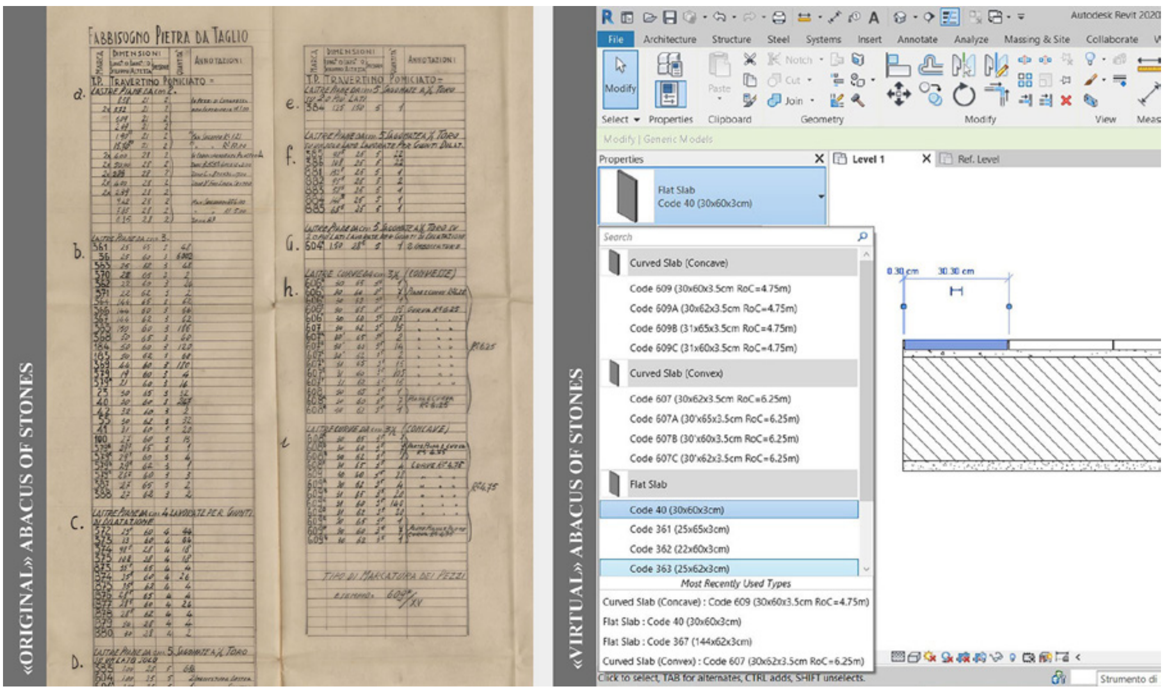


Fig. 8. *From the "Original" Abacus of Stones to the "Virtual" one: the choice of slabs by the Type Selector (MART, Fond "Angiolo Mazzoni", left).*

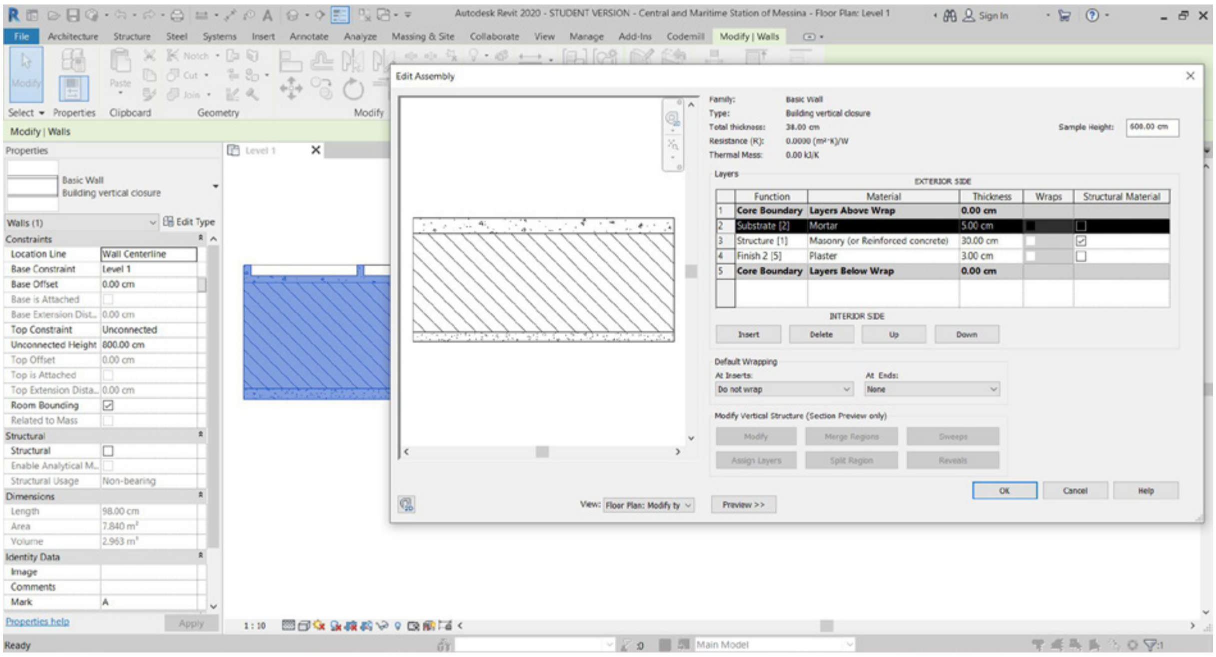


Fig. 9. *Configuration of the shell, a proposal to consider mortar joints.*

The *system family* used to reproduce the "stratigraphy of the envelope except for the finish layer" must be shaped to accommodate the slabs inside and also to consider, expanding the fields of application, the mortar used for the joints. Therefore, a virtual thickness has to be attributed to the mortar layer that must also include the depth of the slabs; in this way, the latter will find their place in the substrate thanks to the void extrusion created in the loadable family (Fig. 9).

A more suitable model has thus been prepared for the management of a stone material facing with the possibility of querying the individual slabs, investigating their properties at a greater level of detail than that of the entire coating system.

However, it is necessary to understand how to attribute diachronic informative contents, thanks to which to confer the qualification of "H-BIM" to a virtual object modelled for existing buildings. The question is how to return and provide documentary evidence of the succession of interventions that have affected the shell and in particular the coating.

One possibility could be glimpsed in the *project phases*. More commonly, this function is used in the case of renovations to highlight demolition and reconstruction operations and therefore to move from a state of affairs to a project configuration. Nevertheless, their application to trace the interventions conducted over time still does not seem so effective [17]. Indeed, although through the *Manage/Phases* command it is possible to introduce those recognised in the Construction History of a building, only one phase can be assigned to an object, without the opportunity of attributing information about actions carried out after the moment of "creation", such as maintenance and restoration. The application for the cladding of the Station of Messina, damaged during the Second World War and subject to several changes in the following decades, has demonstrated the limits of the use of phases to narrate its historical evolution or involution (Fig. 10).

If it is therefore tricky to parameterise the "time" factor, changes of a construction element could be documented by inserting images in the *Properties Panel*. Although this option can be presented as a chance to testify the phases by associating the relative technical and photographic documentation, it is actually a simple collection of digital products that cannot be either organised according to appropriate sorting criteria or described to highlight the peculiarities. This would result in an unstructured data container that would not satisfy the "archival" purposes required to an H-BIM object.

The functions offered by parametric modelling software for existing constructions, especially if historical,

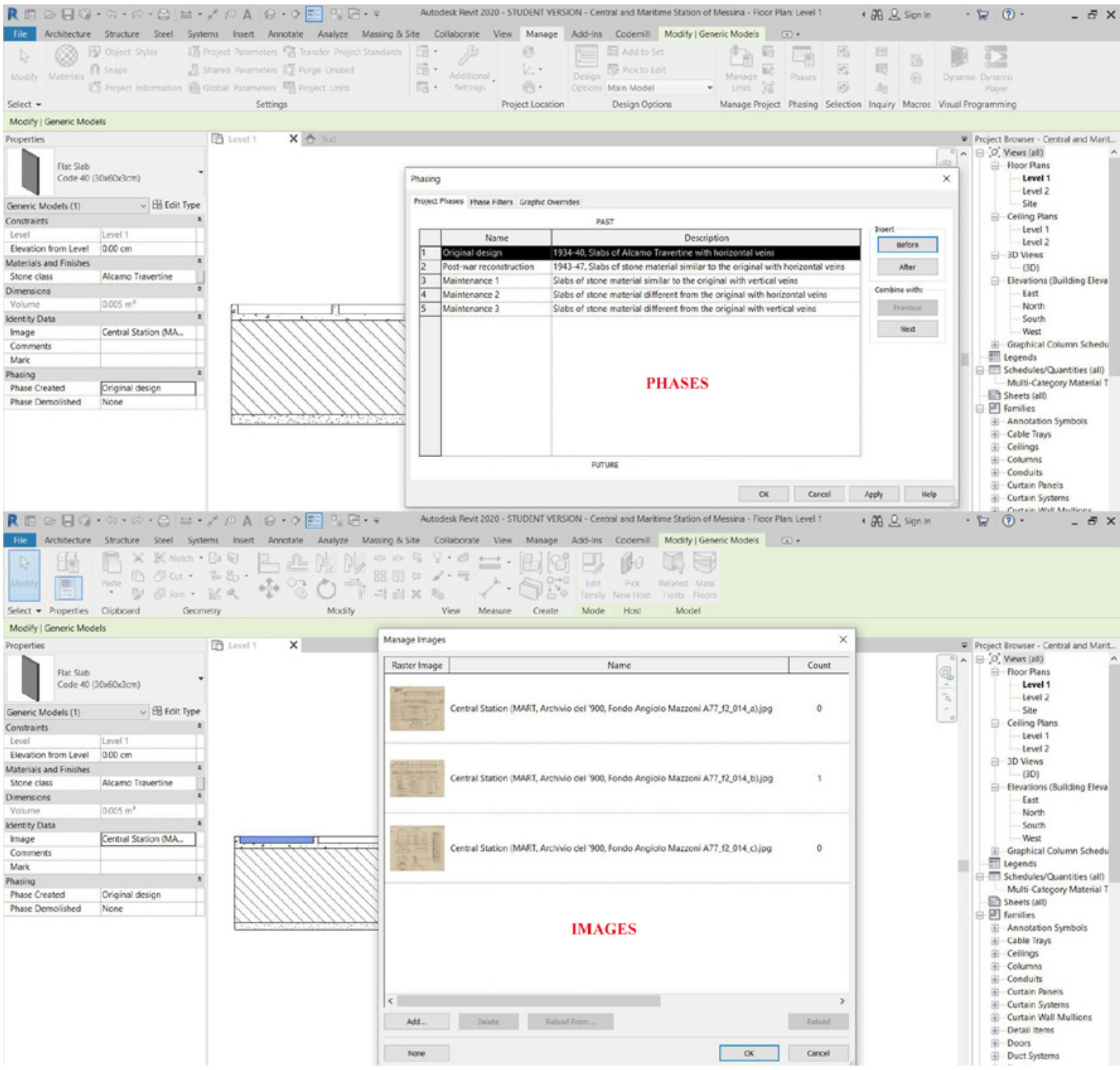


Fig. 10. *The potential "Construction History" in BIM environment: the phases and the images as instance properties.*

are still unfortunately insufficient. The problem does not lie so much in the creation of the virtual equivalent of the construction element as in the type of informative contents that it can accommodate, especially concerning the building past. Tracing interventions would allow conducting, already in the BIM environment, more aware evaluations on which to base and plan the maintenance actions.

4. HERITAGE-BIM, AN OPPORTUNITY FOR THE BUILDING DOSSIER?

A Building Dossier should be configured as a tool for multidisciplinary knowledge of an edifice to analyse its many aspects (structural, technological, and plant engineering), reconstruct its history from origins to the current state of affairs, and benefit from a guide for future interventions. Despite recognising the advantages that would derive from its introduction, it is difficult to proceed with the regulatory implementation due to detractors that underline the burden of its redaction especially for the existing historical buildings [4].

New scenarios seem to emerge with the support of BIM, whose informative inclination is compatible with the necessity of "geometric-dimensional and technical-construction description" required by the operative tool. It is not a coincidence that the Italian standard regarding this methodology, UNI 11337 *Edilizia e opere di ingegneria civile - Gestione digitale dei processi informativi delle costruzioni* (Construction and civil engineering works - Digital management of building informative processes), has dedicated its ninth part to the Building

Dossier. However, its contents are not known because this section has not been published yet [18].

However, it will be necessary to understand whether the "chronicle" needs of interventions carried out over a period can also be contemplated in the modelling. A productive field of experimentation of the interaction between the operative tool and the information technology (IT) one could be represented by the cultural heritage that, in addition to being described from a physical point of view, needs to show history and its changes.

Therefore, Heritage-BIM is not a variation of the BIM methodology but represents a complete approach that satisfies the further need for a more effective "management" of the building and prepares for more adequate Maintenance Plans.

5. ACKNOWLEDGEMENTS

The pictures of the Central and Maritime Station of Messina, used to compose figures 1 and 2, have been kindly provided by the Laboratorio di Studi doCme 1908 of the Engineering Department of the University of Messina. The documentation related to the railway complex and produced in the last decades has been cordially offered by the Direzione Territoriale Produzione S. O. Ingegneria di RFI (Rete Ferroviaria Italiana).

6. REFERENCES

[1] Pavan A, Mirarchi C, Giani M (2017) BIM: Metodi e strumenti. Progettare, costruire e gestire nell'era digitale. Tecniche Nuove, Milano

[2] Ferrara A, Feligioni E (2016) BIM e Project Management. Guida pratica alla progettazione integrata. Flaccovio, Palermo

[3] Pozzoli S, Bonazza M, Villa WS (2018) Autodesk® Revit 2019 per l'architettura. Guida completa per la progettazione BIM. Tecniche Nuove, Milano

[4] Cavallaro L, Cernaro A, Salvo G (2018) Il Case History nel Fascicolo del Fabbricato: contenuti, gestione e strumenti. I suoi contenuti a partire dal patrimonio architettonico messinese. In: Proceedings of the 6th International Conference on the documentation, conservation and recovery of architectural heritage and on landscape protection ReUSO. Gangemi, Roma, pp 279–290

[5] Fiandaca O (2002) Stazione Centrale e Marittima di Messina. In: Aricò N (ed) La penisola di San Raineri diaspora dell'origine, Rassegna di studi e ricerche, 4, Sicania, Messina, pp 347–366

[6] MART (Museo di Arte moderna e contemporanea di Trento e Rovereto), Archivio del '900, Fond "Angiolo Mazzoni", Messina. Stazione Ferroviaria e Marittima: G3 p 55V, A77 fasc. 2.14-2.15, S.L. 26.25

[7] Fondazione FS Italiane, Archivio Architettura FS, Fond "Angiolo Mazzoni", Series 1 "Progetti e studi", Units 8, 9, 14, 15, 16, 17, 18

[8] Cozzi M, Godoli E, Pettenella P (eds) (2003) Angiolo Mazzoni (1894-1979). Architetto Ingegnere del Ministero delle Comunicazioni. Conference Proceedings, Firenze, December 13th-15th 2001. Skira, Milano

[9] Mazzoni A (1934) I nuovi materiali. In: Sant'Elia, a. III, 63, March 15th, p 1

[10] Poretti S (2008) Modernismi italiani. Architettura e costruzione nel Novecento. Gangemi, Roma

[11] Bertolazzi A (2015) Modernismi litici 1920-1940. Il rivestimento in pietra nell'Architettura Moderna. Franco Angeli, Milano

[12] Fiandaca O, Margagliotta A (1999) Architettura e architetti negli anni trenta in Sicilia. Il problema del rivestimento. In: Casciato M, Mornati S, Poretti S (eds) Architettura moderna in Italia. Documentazione e conservazione. Edilstampa, Roma, pp 581–593

[13] Cernaro A, Fiandaca O (2019) I rivestimenti lapidei autarchici a Messina. Dall'analisi critica dei restauri condotti alla previsione di un "corretto" Piano di Manutenzione. In: Proceedings of the 7th International Conference on the documentation, conservation and recovery of architectural heritage and on landscape protection ReUSO. Gangemi, Roma, pp 1439–1450

[14] FS Compartimento di Palermo-Sezione Lavori (1947) Messina 1943-1947, la ricostruzione ferroviaria. Pezzino & F, Palermo

[15] Istituto Superiore per la Conservazione ed il Restauro - MiBACT (Ministero per i beni e le attività culturali e per il turismo), Informative System "Vincoli in Rete": Search for administrative documents of the Stazione Marittima di Messina, Decree of protective restriction of June 19th 2002 (D.Lgs. 490/1999) http://vincoliinrete.beniculturali.it/VincoliInRete/vir/vincolo/dettagliovincolo168242. Accessed May 2020

[16] BIM-Object online sharing platforms: bimobject.com; bim.archiproducts.com; syncronia.com. Accessed May 2020

[17] Maltese S (2017) Il fascicolo in un processo di progettazione e costruzione BIM. In: Dejaco MC, Maltese S, Re Cecconi F (eds) Il fascicolo del fabbricato. Maggioli, Rimini, pp 167–194

[18] UNI 11337 "Edilizia e opere di ingegneria civile - Gestione digitale dei processi informativi delle costruzioni", parts published on the official page of the UNI Ente Italiano di Normazione: 1: 2017; 4: 2017; 5: 2017; 6: 2017; 7: 2018 http://store.uni.com/catalogo/catalogsearch/result/?q=uni+11337&fulltext=fulltext&tpqual%5B0%5D=1a&tpqual%5B1%5D=9&tpqual_var=99&ttbloc=0. Accessed May 2020

OPERATIONAL ATLAS OF EXPOSED MORTARS AND CONGLOMERATES FOR INTERVENTIONS ON THE WIDESPREAD ARCHITECTURAL HERITAGE

TEMA
Technologies Engineering Materials Architecture
e-ISSN 2421-4574
Vol. 6, No. 2 - (2020)

Sara Fasana, Marco Zerbinatti, Alessandro Grazzini, Federico Vecchio

DOI: 10.30682/tema0602h

Highlights

Prepare an operational atlas of traditional mortars and conglomerates. Recover the historical technological knowledge of materials for exposed surfaces. Innovate traditional techniques and methods with *ad hoc* formulations. Encourage the use of materials compatible with common heritage buildings. Promote the methods of choice and action that prioritise circular construction.

Abstract

When it comes to Science Heritage, the availability of refined investigation techniques, an advanced knowledge of the characteristics of materials, the current technological capacity and the synergy of specialised operators, coordinated into multidisciplinary teams, guarantee, with the support of cutting-edge tools, excellent results for every conservative operation applied to monumental buildings of acknowledged interest. On the contrary, there are still strong limits to the likelihood that this excellence will reverberate on the multitude of interventions performed on widespread architectural heritage. The research project underway envisages the preparation of an operational atlas of reference for exposed mortars and conglomerates, based on the historical and technological knowledge of materials (particularly those available locally) complete with experimental data on constitution and performance, which is useful to support the development of compatible maintenance and conservation procedures.

Keywords

Mortars, Conglomerates, Mechanical behaviour, Maintenance, Innovative method, Operational atlas.

Sara Fasana*
DISEG - Dipartimento di Ingegneria Strutturale, Edile e Geotecnica, Politecnico di Torino, Torino (Italy)

Marco Zerbinatti
DISEG - Dipartimento di Ingegneria Strutturale, Edile e Geotecnica, Politecnico di Torino, Torino (Italy)

Alessandro Grazzini
DISEG - Dipartimento di Ingegneria Strutturale, Edile e Geotecnica, Politecnico di Torino, Torino (Italy)

Federico Vecchio
DISEG - Dipartimento di Ingegneria Strutturale, Edile e Geotecnica, Politecnico di Torino, Torino (Italy)

** Corresponding author:*
e-mail: sara.fasana@polito.it

1. INTRODUCTION

Historical mortars and conglomerates are a distinguishing element in the image of historic buildings; as such, they represent a key aspect in their conservation. In particular, the choice of material is an essential step in the correct orientation of any maintenance, recovery or conservation work, ensuring compatibility, effectiveness and durability over time [1]. The investigation methods used for the characterisation of historical mortar samples taken on-site (from monuments or buildings of high cultural and environmental value) are well established and widely documented in the literature. The direct aim of the investigation phases (Fig. 1) is to support, on a case by case basis, the specific formulation of the material used for integration (or, more rarely, replacement), be it for exposed surfaces, to support the finishing or to assist the load-bearing functions. That described is a

Fig. 1. *Serralunga di Crea, Sacro Monte, Chapel 1. A sampling of external render on the south façade (left); Sample 11 (top right); aggregates from disgregation of sample 11 (bottom right).*

fundamental moment in the design of each operation, in the case of buildings subject to specific protective measures. On the other hand, it is rarely implemented in the case of widespread architectural heritage, even though these buildings extensively characterise every local cultural- environmental system considered as the ambitus, on a par with elements of recognised monumental value (Fig. 2).

This critical aspect highlights the need to implement effective programmes aimed at the development of innovative instruments for coordinating research, in order to promote the sharing and dissemination of the most advanced knowledge so that it is accessible and applicable on a broader scale, involving and raising awareness among the numerous parties directly concerned with widespread heritage.

For the coordination and innovation of scientific research into the more general matter of Science Heritage, for example, a widespread research infrastructure, which is strategic for Europe, has been set up for some years now: it consists of a network of laboratories and state-of-the-art instrumental resources, physical and advanced digital archives, widely distributed throughout the territory. This platform, made available to the scientific and manufacturing community, makes it possible to support high-level research, supporting innovation and consequently the competitiveness of the reference market, by sharing cutting-edge instrumental resources in the new multidisciplinary field of cultural and natural heritage science [2]. Numerous projects respond to the need to integrate skills and effectively propagate knowledge, usually by creating “scalable” databases, the architecture of which increasingly makes use of the potential for interoperability with resources for the modelling of information related to spatial entities. [3–5]. Lastly, there are plenty of projects that focus on more specific research topics, such as the classification and characterisation of traditional building materials of historical and cultural interest: the knowledge of the historical and technological value of the materials used can represent a research

Fig. 2. *Serralunga di Crea, Sacro Monte, Chapel 1. Main façade (right) and damage at the base of the northern façade (left).*

strategy, to develop more efficient ways to use them and to refine conservation and restoration methods [6, 7].

None of these instruments, however, can effectively meet the requirements of "accessibility", "technology transfer" and extended applicability of results. The possibility that excellent research methods and results can significantly affect the quality of maintenance, conservation and recovery of widespread heritage is still generally very limited. The phases that govern their conduct, from the diagnostic project to the choice of material and its final application, are often affected by different and concomitant errors or shortcomings. This means that in a present in which the progress of knowledge is supported by the availability of refined investigation and analysis procedures and in a technological context which would make it possible to fulfil the production of very high-quality materials, it is becoming increasingly complex to operate in such a way as to limit the repetition of operations that soon turn out to be ineffective [8, 9].

The causes of these failures often depend on design shortcomings, which are then reflected in the subsequent phases with the choice and application of inappropriate materials.

From a theoretical point of view, it is necessary to fill the current gap between "knowing and doing" by disseminating the method and *applied technological documentation*. The current multiplication of responses on the market and the apparent availability of "new" and easy to apply products, must be supported by a solid and widespread *basic knowledge*.

In more general terms, it is necessary to work case by case to guide the choice towards materials which, while respecting (or approximating) the current regulatory requirements, reconcile the constitutional requirements (which derive from the intrinsic characteristics and are also expressed in the value of image), with the performance requirements (which take into account the complex characteristics of the substrate, e.g.: the weaving/construction of walls, expressed in behaviour): resulting in compatibility.

The complex methodological framework, the criticalities and the goals outlined, with reference to all the interventions on the existing heritage for conservation purposes, can similarly be applied to those aimed at the "innovation of existing elements", or to new constructions.

For example, we cannot overlook the fact that a wide range of currently available materials, formulated in response to the application of modern Bio-Eco compatibility assessment protocols, also draw extensively on technological knowledge already consolidated in ancient times. It is now widely recognised the intrinsic ability of materials (historically derived from the use of locally available raw materials) to meet "sustainability" criteria (ante litteram). In this case also, the "quality" of the product represents a necessary condition but is not sufficient to guarantee the "quality" of the interventions (there are no such things as "good" and "bad" materials, there are materials that are suitable for the specific case, which must be applied correctly): the expected effectiveness can be compromised by incorrect application cycles and, even before that, by the proven incompatibility of the material chosen with the characteristics of the "modern" supports to which they are to be applied.

It is on the basis of these reflections and the current state of the art that two main requirements are outlined.

The first, methodological: it is necessary to reconcile the knowledge of tradition with the know-how brought about by innovation. The second, of a practical application type: it is necessary to further the knowledge of historical mortars and conglomerates in order to accompany the results of the constitutional analysis (consolidated in terms of the method and with a good level of dissemination of the results) with those of the performance analysis, with particular reference to the mechanical behaviour.

This contribution outlines the methodological approach for setting up an operational tool, in the form of an atlas, for the current selection and application of traditional local mortars and conglomerates, in response to the first requirement. It illustrates the results of a phase of experimental tests for the mechanical characterisation of traditional mortars, in response to the second requirement.

2. FROM THE KNOWLEDGE OF TRADITIONAL TECHNIQUES TO THE DEVELOPMENT OF EFFECTIVE OPERATING METHODS AND SUITABLE APPLICATION SOLUTIONS

The investigations underway represent a specific development of the general topic of masonry surfaces in historical buildings, with particular reference to the renewed knowledge of historical materials and techniques. Previous research developed at the Department of Structural and Geotechnical Building Engineering (from now on DISEG, formerly Department of Building and Territorial Systems Engineering) of the Politecnico di Torino, on the general topic of masonry surfaces in historical buildings, has produced significant results, including the Permanent Collection in two sections, "Natural dyes and earth-based dyes" (prepared by G.P. Scarzella) and "Review of local sands and mortars". These researches were launched with the main goal of recovering and documenting materials, principles and operational criteria of tradition (on the basis of scientific knowledge) necessary and essential for the development of compatible procedures for conservation, by virtue of their documentary value and technological testimony, together with their recognised environmental cultural value. The materials exhibited in the two sections are organised into homogeneous territorial areas (also respecting the geopolitical subdivision of the pre-unification Italian territory).

The materials displayed in the two sections of the DISEG collections are arranged according to homogeneous territorial areas, in keeping with the need to document the wide variety of solutions and image values associated with the historically consolidated use of local materials, creating a solid conceptual basis for the subsequent definition of an Atlas.

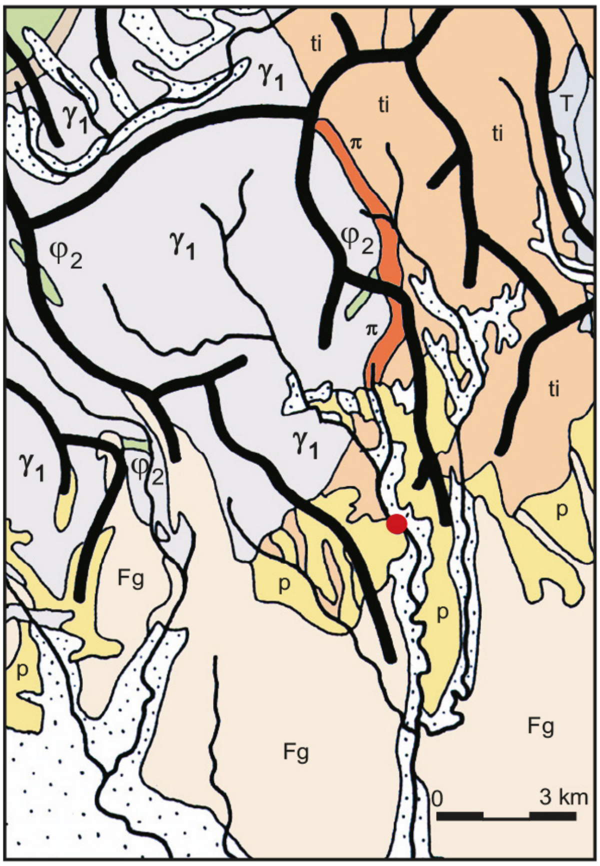
Also with reference to specific solutions prepared for conservation interventions on widespread heritage, each element of the rich collection is accompanied by samples of original materials (historical mortars or plasters collected on-site, also from study sites), samples of local sands sifted according to different grain size classes (Fig. 3) and the respective laboratory samples obtained from specific formulations (with the definition of appropriate grading curves).

The collection and cataloguing of local sands used historically are continuously increased, both with systematic procedures for territorial areas and with reference to further analysis for case studies dealt with gradually during research projects.

The knowledge acquired through the research mentioned in abstract form the basis for the definition of specific suitable and effective application solutions. Numerous experimental studies have been carried out for the

Fig. 3. *Sands from the DISEG permanent collection, sampled at (from left to right): Ostola creek, near Masserano; San Damiano, loc. Caminello; San Damiano, loc. Caminello, from a different geological stratification; Varaita creek, near Fontanile; Toce river, at Crevola d'Ossola.*

characterisation of historical mortars and conglomerates, including fatigue tests and thermo-hygrometric tests to identify, case by case, the most durable repair mortar compatible with a specific historical masonry. The experimental characterisation phase and the subsequent formulation of ad hoc mortars made it possible to effectively support the choice of the most compatible material in important restoration sites [10].



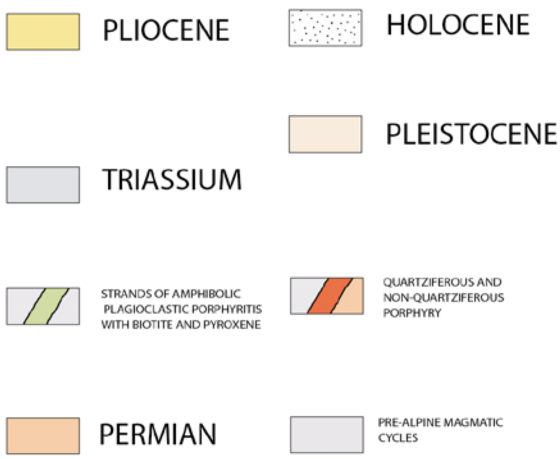


Fig. 4. *Masserano, Ostola creek; geological map and related key.*

3. METHOD AND STRUCTURE OF THE ATLAS

The methodological approach and the consolidated results of the research illustrated in paragraph 2 form the solid basis for the current in-depth study, which slots into the international scientific debate in an organic and dialectical way, sensitive to the topic of the characterisation of mortars as a specific and foundational phase for the activity of each restoration site [11–13].

The set of reference data (composition, grading curve, constitutional characteristics, experimental results for physical and mechanical characterisation, data on compatibility with different types of the substrate) will be progressively arranged into a methodological, operational and interactive tool, aimed at supporting the investigation phases and, consequently, at effectively guiding the choice of the most suitable material for the specific case, from the point of view of aesthetic, physical-chemical and mechanical compatibility. The deposit of georeferenced data, both with reference to the geographical location of the structures in our case studies and, particularly, the place of origin of the local material used historically and subject to analysis; or, again, to the location of historical and current quarrying sites. Such mapping, in relation to special cartographic levels, mainly geological, will make it possible to identify possible horizons common to different areas, favouring the use of materials similar to those historically quarried, even in the absence of sites that are still active (Fig. 4).

From an operational point of view, the architecture of the data in the atlas, and particularly the way in which its scientific and technological contents are consulted and

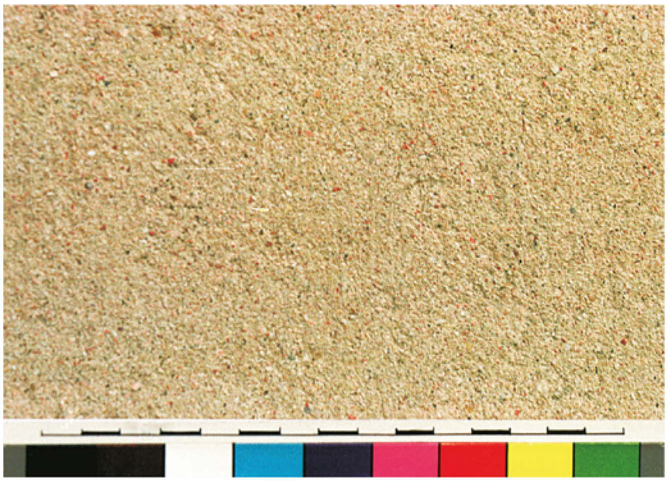


Fig. 5. *Image of an external render of the apse of a local church (see the red sand a) shown in Fig. 3, the sampling point of which is the red point on the map shown in Fig. 4.*

integrated, will allow different possibilities of interaction, also as a consequence of the characteristics of each intervention.

With particular reference to work on existing structures, from the methodological point of view there are four different operating methods (in relation to the possible boundary conditions) of "utility" (the language and coding used in the description of this paragraph are functional to the structure of the data architecture of the interactive tool):

A) interventions of excellence, with the possibility to:

- carry out in-depth diagnostic surveys;
- ormulate a suitable material ad hoc;
- define specific operational application methods.

In this case, an out-in-outnew-in procedure is developed:

- out: comparison and methodological support in choosing surveys, based on similar cases catalogued in the atlas;
- in: deposit of the knowledge gained from the case-study in question;
- outnew: support with the elaboration of the formulations ad-hoc;
- in: deposit and cataloguing of the innovative formulation produced for the case-study in question.

B) interventions with:

- the possibility to carry out diagnostic surveys based on a specific survey project;
- the need to use pre-formulated solutions and operational methods that have already been outlined;

In this case, an out-in-outchoose procedure is developed:

- out: comparison and methodological support in choosing surveys, based on similar cases catalogued in the atlas;
- in: deposit of the knowledge gained from the case-study in question;
- out-choose: support with the choice of the material, based on the specific formulations catalogued in the atlas.

C) interventions without:

- the possibility to carry out diagnostic surveys;
- and with the need to use premixed solution, resorting to defined executive methods;

In this case, an out-outchoose procedure is developed:

- out: identification of the most similar case among those catalogued in the atlas;
- out-choose: support with the choice of the material, based on the specific formulations catalogued in the atlas.

D) interventions without:

- the possibility to carry out diagnostic surveys;
- and with the possibility to use locally available materials mixed at the time of use by experts with full knowledge of the traditional techniques.

In this case, an out-out.in- outchoose procedure is developed:

- out: identification of the most similar case among those catalogued in the atlas;
- out.in (the atlas can be enriched with new case-histories);
- out-choose: support with the choice of the material, based on the specific formulations catalogued in the atlas.

Common to each type of utility will be the systematic deposit of documentation in the appropriate appendix: quali-quantitative, in cases A), B) and D), or qualitative only, in case C). The aim of this is to monitor the behaviour of the individual materials over time, in relation to the physical and environmental context of their application, which is conditioned by the implementation procedures.

The project of the operational scientific atlas is accompanied by an experimental research activity planned in the laboratory. Numerous mixtures of mortars characterised by a single aggregate distribution curve as project invariable are being formulated and packaged. The sand used is siliceous and comes from Pliocene deposits of the Tertiary Basin in Cisterna d'Asti. More precisely, they consist of Pliocene sediments. Asti Sands - Alternating sand - clay (Villafranchiano) and are more or less stratified yellow sands, with gravelly layers and marly, calcarenite and calcirudite intercalations; microfauna – in the marly interlayers – in Bolivina (Geological Map of Italy, 1:100,000, sheet 69). Material is taken from the Bricco Toni quarry. (http://193.206.192.231/carta_geologica_italia/tavoletta.php?foglio=69). The sand is wet sifted in the quarry so that it can be classified for industrial production purposes. In the laboratory, new sifting and mixing operations are carried out to ensure that the distribution of aggregates is always uniform.

Mixture variables are the types of binder and binder/aggregate ratios. 30 standardised specimens are produced for each type of mixture, and mechanical characterisation tests are carried out. The specific aim is to obtain numerical reference values for the different types of mortar, to be used with different types of substrate.

This provides a useful tool for operators already in the preliminary decision-making process of planning interventions.

4. TYPES OF MORTARS AND THEIR BEHAVIOUR: FROM THE FORMULATION OF THE MIXTURE TO PERFORMANCE CHARACTERISATION

Once a solid methodological basis has been established, the effectiveness of an operational tool requires simplified criteria, to guarantee its applicability, also modulated according to different levels of detail (potentially different for each situation). Similarly to the synthetic identification of the possible cases of intervention outlined in the previous paragraph 3, it is, therefore, necessary to accompany the atlas with multiple criteria for the classification of material, functional to the construction of a reference matrix to outline complex paths according to the different combinations that are possible. Sensitivity and preparation of all those involved, the specificity of the case, conditions and criticality of the context will help guide the approach, influencing the quality of the results achieved. A specific component of the atlas consists of a guide to the correct and unambiguous identification and classification of types of mortar and conglomerate, with the aim of outlining the variety and complexity behind said classification, also appropriately reconciling the legislative data. This is why it is essential to envisage the preparation of a "connection" that leads to the definition of a limited range of suitable solutions, among those available and is continuously harmonised and updated (The main lexical references used as terminology and definitions are referable to the standards in force in the sector, such as – by way of non-limiting example: UNI 10924:2001, UNI EN 1015:2007 and subsequent updates).

The specific aims of the research include the assessment of the mechanical characteristics (resistance to compression and flexion, dynamic elastic modulus and

Fig. 6. *DISEG Laboratory storage. Sets of mortar specimens of Group 1 (standard size, according to UNI EN 1015:2007).*

static elastic modulus) of mortars formulated with reference to traditional types of mortar among the most common and widespread in the historical building industry. Mortars were formulated and produced for a test campaign (Group 1): three sets of specimens (Fig. 6) were prepared (in two series: a - standard size 40x40x160 mm [according to UNI 1015:2007] and b - size 30x30x300 mm), respectively: set I) for 28-day tests; set II) for 120-day tests; set III) for the cataloguing and archiving of the material inventory that accompanies the atlas. The results of the tests carried out on this set of samples (28-day tests) are presented in paragraph 5 below.

Additional phases are currently being developed:

- characterisation of the second set of specimens, stored in an uncontrolled environment;
- packaging of the samples in Group 2;
- replica of two sets (IV) and (V) of samples from Group 1, for ageing in a climatic chamber (T and RH checked with cycles at pre-set intervals) and subsequently testing for mechanical characterisation, in order to compare the results obtained from the tests on set II (in an uncontrolled environment at 120 days).

At the end of Phase Two, when it is considered that the amount of experimental data available can be considered statistically significant, a specific transversal phase will be launched, aimed at verifying known methods for the dimensional reconfiguration of samples to undergo mechanical behaviour tests, for the comparison and validation of results [14].

5. THE EXPERIMENTAL RESULTS OF SET I

For each formulation of Group 1 mortars, test specimens of set I) underwent laboratory tests to determine the modulus of elasticity using an ultrasound device. The tests (ultrasound test is described by UNI EN 12504-4: 2005) were carried out both on standardised specimens and on specimens measuring 30x30x300 mm.

This non-destructive and repeatable survey allows various observations [15]; the flight times obtained were used to calculate the dynamic modulus of elasticity *Ed,* according to (1):

$$Ed = vm^2 \cdot \rho m \qquad (1)$$

where *vm* is the mean propagation speed (m/s), ρm the mean density of the material considered (kg/m^3).

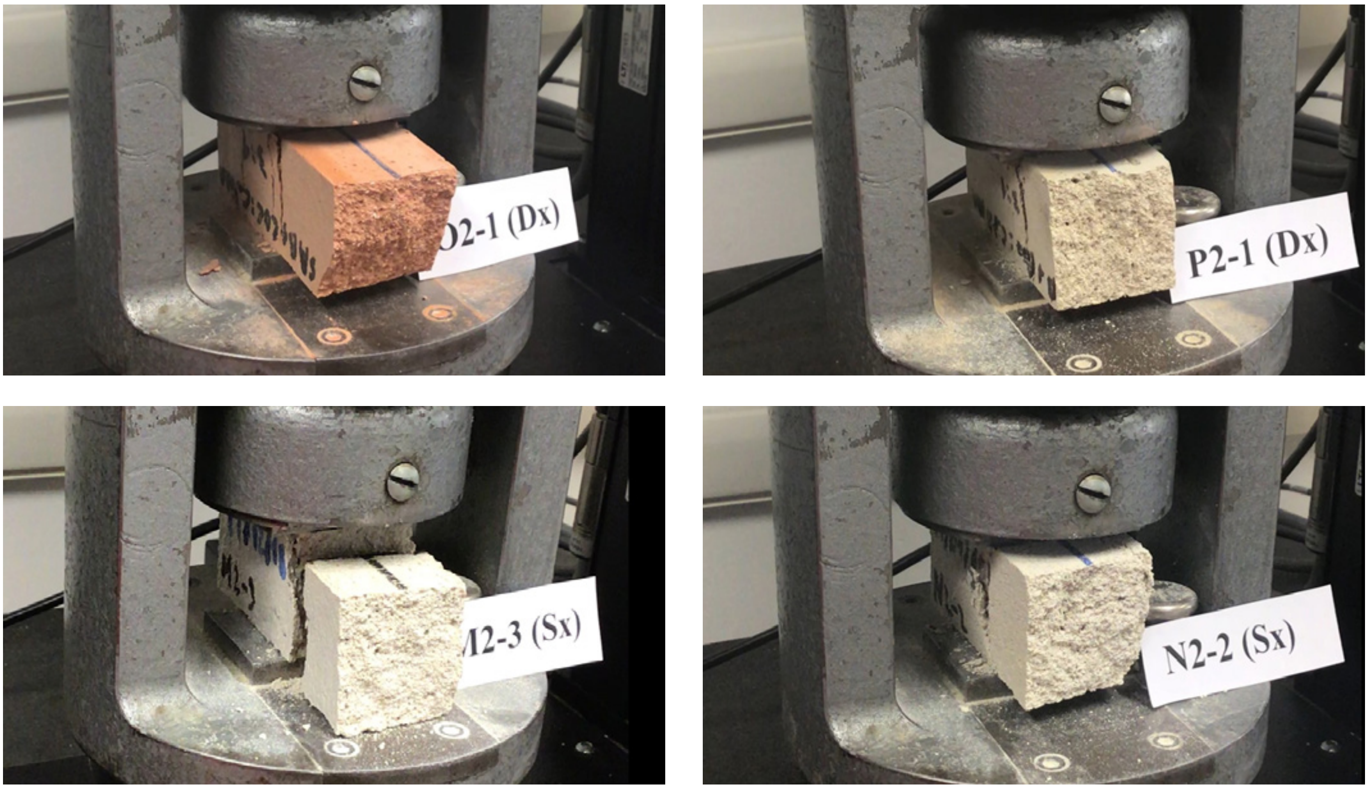


Fig. 7. *Samples of set I, Group 1 tested to compression resistance according to UNI EN 1015-11:2007.*

The set of samples with the highest mean *Ed* value consists of cement or cement and lime putty (category H), with the exception of samples for which the amount of lime putty is predominant compared to cement (H4 and H8). In general, the high speed of the formulations corresponding to categories H and O2 is probably due to the fact that the samples have a high density. On the other hand, the lowest absolute values of *Ed* were recorded by the specimens made with hydraulic lime (category G). Comparing the values of mortars G1 and G2 it was possible to see how the amount of hydraulic lime in the mixture influenced the *Ed* value; the aggregate/binder ratio influenced the density of the samples, which is directly proportional to *Ed*.

For a comparison with the experimental results of the elastic modulus, the flexion and compression resistance tests described in UNI EN 1015-11:2007 (Fig. 7) were also performed (first set of specimens) [16]. The results of the resistance to compression (Fig. 8), confirmed a tendency towards values already observed in the measurement of the dynamic elasticity modulus.

The first results of the flexion tests (performed with three substrates) on mortars G-H-I-L also confirmed the trend detected by the results of the remaining formulations, and therefore the mechanical characteristics previously obtained.

6. DISCUSSION OF THE RESULTS AND PROSPECTS

The elastic modulus of materials is of great importance, especially in the presence of coupled materials (e.g. in the case of plaster applied to masonry or mortar for bedding joints). As the mortar applied on-site starts to set and harden, it is inevitably subject to shrinkage, which can cause deformations (albeit controlled), only partially transmitted to the masonry. The coupling and the bond between the original masonry substrate and the restoration mortar inevitably create deformations of the materials when they are subject to different types of cyclic stress (thermo-hygrometric or mechanical) linked to their working life [17]. We know that the value of these deformations is proportional to the elastic modulus of the material; to prevent possible recurring problems, it is necessary for there to be adequate mechanical compatibility between the two materials [18]. In general, the results obtained with the test campaigns have confirmed the values expected for each group of mixtures; with reference to the most common types of masonry substrate [19, 20] of widespread heritage (bricks, mixed masonry such as listed or ordinary masonry in compliance with Savoy specifications) the first results obtained already offer the possibility to guide design choices.

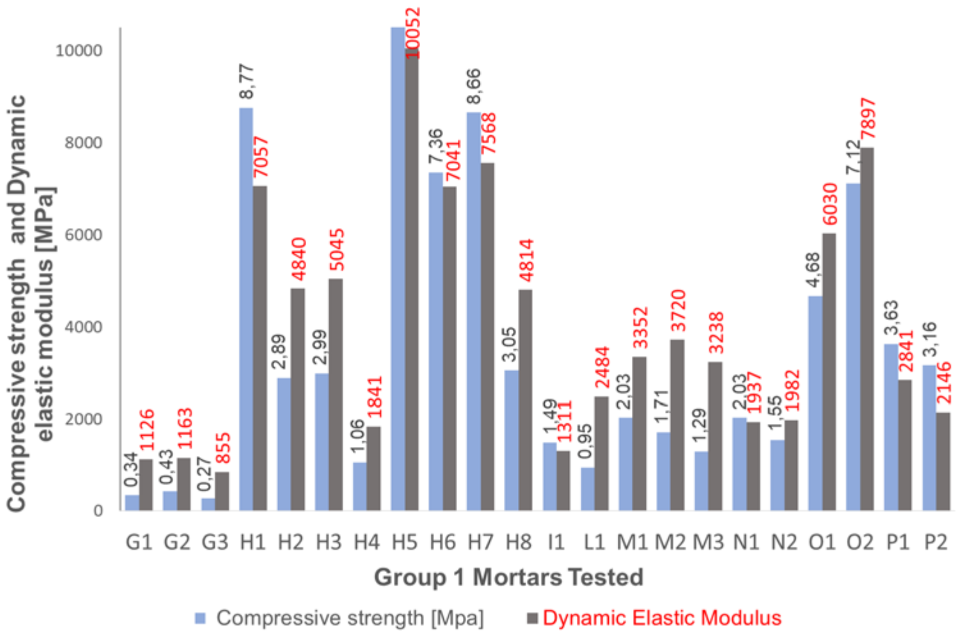


Fig. 8. *Medium values of compressive strength and dynamic elastic modulus for each mortar composition of set I, Group 1.*

As a second approximation, differences in binder and binder/aggregate ratios (e.g. mortar type G3, for the group of mortars with hydraulic lime) make it possible to refine the knowledge of the mechanical properties of a larger number of mixtures; in practice, this makes it possible to better approximate the behaviour of the pre-existing homologous material.

Given the importance of the requirement in question for the durability of any maintenance, conservation or consolidation work, the atlas under construction will be accompanied by reference values of the elastic modulus of the mortars investigated.

The framework of needs and contextual conditions, to which employees must refer, is complex and articulate: the effective coordination of knowledge is a strategic condition to ensure a high-quality level of work. The operational atlas is proposed as a methodological and practical tool, with the ambitious aim of helping fill the current gap between “knowing and doing” from the bottom up.

The set of data collected and arranged will be able to support the survey phases, and the choice and application of mortars and conglomerates to respond to the needs and critical issues of specific construction sites.

7. REFERENCES

[1] Santos AR, Veiga MdR, Matias L, Santos Silva A, De Brito J (2018) Durability and Compatibility of Lime-Based Mortars. The Effect of Aggregates. Infrastructures 3(3): 34. https://doi.org/10.3390/infrastructures3030034

[2] Cano E, Ramirez Barat B (2017) European research Infrastructure for heritage science: from Iperion to E-Rihs. In: Rogeiro-Candelera MA, Mosquera MJ, Gil MLA (eds) Technoheritage 2017 Programme and abstract. Cadiz, Spain, p 85

[3] Chiabrando F, Colucci E, Lingua A, Matrone F, Noardo F, Spanò A (2018) A European Interoperable Database (EID) to increase resilience of cultural heritage. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XLII-3/W4: 151–158

[4] Gattuso C, Mirocle Crisci G (2008) Il piano diagnostico tradizionale e la procedura informatizzata DIMA. In: Atti del convegno Arkos_2007 “La diagnostica intelligente”, Università della Calabria, Dipartimento di Scienze della terra, Cosenza, 28-29 June, 2007. Syremont, Cosenza, pp 21–27

[5] Mirocle Crisci G, Gattuso C, Miriello D, Francolino S (2008) La raccolta e l’elaborazione dei databases nel progetto DIMA. In: Atti del convegno Arkos_2007 “La diagnostica intelligente”, Università della Calabria, Dipartimento di Scienze della terra, Cosenza, 28-29 June, 2007. Syremont, Cosenza, pp 29–37

[6] Santos Silva A, Lima J, Veiga MdR DB-Heritage: Database of building materials with historical and heritage interest. (Base de dados de materiais de construção com interesse histórico e patrimonial - PTDC / EPH-PAT / 4684/2014). http://db-heritage.lnec.pt/

[7] Santos Silva A, Giollo R, João Correia M, Veiga MdR, Faria P (2019) DB- Heritage: A database of mortars composition and characteristics. In: RILEM, Proceedings of the 5th Historic Mortars Conference 130, pp 516–528

[8] Bocca P, Grazzini A, Masera D (2011) Fatigue behaviour analysis for the durability prequalification of strengthening mortars. In: Journal of physics. Conference series 305 Damage Assessment of Structures (Damage in concrete structures 012041). University of Oxford. http://dx.doi.org/10.1088/1742-6596/305/1/012041

[9] Bocca P, Grazzini A (2011) Durability evaluation of strengthening mortars applied to historical masonry structures. In: Zachar J, Claisse P, Naik TR, Ganjian E (eds) Proceedings of the 2nd International Conference on Sustainable Construction Materials and Technologies 3, pp 1419–1429

[10] Formia A, Serra CL, Zerbinatti M, Tulliani JM (2014) The plasters of the Sacro Monte of Varallo Sesia. From the characterisation to the proposition of a restorative mix. In: Case Studies in Construction Materials 1: 46–52 Elsevier. 10.1016/j.cscm.2014.04.001

[11] Freire T, Silva AS, Veiga R, De Brito J (2010) Characterisation of Portuguese historical gypsum mortars: a comparison between two case studies. In: Materials Science Forum 636-637: 1258–1265

[12] Veiga R, Fragata A, Velosa AL, Magalhaes AC, Goreti M (2010) Lime-based mortars: viability for use as substitution renders in historical buildings. In: International Journal of Architectural Heritage 4: 177–195

[13] Veiga R, Silva AS, Tavares M, Santos AR, Ampreia N (2013) Characterisation of renders and plasters from a 16th Century Portuguese Military Structure: chronology and durability. In: Restoration of Buildings and Monuments 19-4: 223–228

[14] Magalhães A, Veiga R (2009) Physical and mechanical characterisation of historic mortars. Application to the evaluation of the state of conservation. In: Materiales de Construcciòn 59(295): 61–77. doi: 10.3989/mc.2009.419070

[15] Grazzini A, Zerbinatti M, Fasana S (2019) Mechanical characterisation of mortars used in the restoration of historical buildings: an operative atlas for maintenance and conservation. In: IOP Conference Series: Materials Science and Engineering 629: 1–7. http://dx.doi.org/10.1088/1757-899X/629/1/012024

[16] Standard UNI EN 1015-11:2007 Metodi di prova per malte per opere murarie - Parte 11: Determinazione della resistenza a flessione e a compressione della malta indurita

[17] Bocca P, Grazzini A (2013) Mechanical properties and freeze-thaw durability of strengthening mortars. In: Journal of Materi-

als in Civil Engineering 25: 274–280. http://dx.doi.org/10.1061/(ASCE)MT.1943-5533.0000597

[18] Bocca P, Valente S, Grazzini A, Alberto A (2014) Detachment analysis of dehumidified repair mortars applied to historical masonry walls. In: International Journal of Architectural Heritage 8: 336–348. http://dx.doi.org/10.1080/15583058.2013.826304

[19] Margani L (2013) Le murature antiche e principi di forma, geometria, decorazione, costruzione, stabilità. Ed. Lussografica, Caltanissetta

[20] Zerbinatti M, Bianco I, Fasana S, Nelva R (2014) Recovery of stone architectural heritage. In: International Masonry Society ID1459: 1–8