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Modern Construction in Bologna. The Faculty of Engineering by Giuseppe Vaccaro, 1932 - 1935

Giorgia Predari¹, Davide Prati¹ and Angelo Massafra¹

¹ Department of Architecture, University of Bologna, Italy
giorgia.predari@unibo.it
davide.prati5@unibo.it
angelo.massafra2@unibo.it

Abstract.

The Faculty of Engineering is considered a jewel of local rationalist heritage since it follows the main principle of Modernism, namely that “form follows function”, meaning that design should come directly from the purpose.

The aim of maximum functionality is perfectly expressed in the building, thanks to the comb-like scheme adopted for the layout, which is the most effective solution to the internal distribution problem for a school building complex.

The use of industrial systems and materials for the most advanced plant equipment, the innovative nature in finishing components, and the refusal of decorations thanks to introducing a reinforced concrete structure, definitively confirm its compliance with the principles and the lexicon of Modern Architecture.

The whole result is a solid architecture based on the balance between the static nature derived by the full masses and the typical dynamic sense of layout articulation and windowed façade s.

After 85 years of its construction, the most obvious problem related to its conservation is material degradation, especially in those parts affected by transformations or more fragile due to their construction features. One of them is the library tower, where marked phenomena of material degradation must be solved. Recently, its accurate survey, carried out using Terrestrial Laser Scanning techniques and photogrammetric reconstruction, has allowed the understanding of its construction characteristics, especially for the western façade. It was originally made of glass bricks and later replaced by a semi-prefabricated structure whose features and installation methods have never been documented.

Keywords: Construction History, Modern Architecture, Faculty of Engineering, Giuseppe Vaccaro, Terrestrial Laser Scanning, Bologna.

1 Introduction

In the 1920s, Italian architecture was dominated by two different tendencies, which were based on standard technical features: on the one hand, rationalist architecture represented the Modern Movement, according to the European functionalist trends; on the other hand, the monumental style, which was adopted by architects close to the fascist regime, to spread its ideals among the masses and transmit its grandeur. Marcello Piacentini was the greatest ideologist of the monumental trend, and his connection with the regime triggered an intense debate after the Second World War.

Giuseppe Vaccaro's figure remained in the background at the beginning of the studies on the history of Twentieth-century architecture, maybe precisely because of his initial collaboration with Piacentini or, on the contrary, for their consequent conflicts. However, in the last decade, his professional activity has been investigated with renewed attention as a past century crucial experience. Since the 1930s, he has been able to decline Modern architecture with absolute originality and autonomy from cultural and ideological alignments.

Nowadays, we can affirm that Giuseppe Vaccaro [1, 2, 3] was one of the protagonists of Twentieth-century Italian architecture, thanks to his intense professional activity, that has left representative examples of how modern technology, compositional and practical knowledge can be combined with the monumentality of recognizable and prestigious buildings.

In the 1930s, Vaccaro worked mainly in two Italian cities: in Rome, which was the center of the national debate on Modern Architecture, and in Bologna. The latter was still a peripheral city where notable buildings broke into local construction practice only when modernity became the State's official style, enriching architecture with new meanings. Among these, the jewel of rationalist architecture was the Faculty of Engineering building, designed in 1932 by Giuseppe Vaccaro and built by 1935.

At that time, Italian technical culture had recently embraced the changes in building methods introduced by the use of reinforced concrete, which became the tool to embody the characteristics of Modern Architecture. However, the stylistic choices adopted for the building were only apparently coherent with the contemporary European trends. They depended mainly on Vaccaro's personality when the Italian architecture was suspended in a kind of dualism between a celebratory style and a rationalist principle.

After years of study, the building is still subject to analysis and research regarding its significance in the history of Italian architecture and its construction features, making it a prominent building in the history of Modern construction. Its knowledge is being progressively implemented by the fundamental contribution of two parallel activities: archival research, which represents the basis of all historical investigations, and on-site investigations and direct surveys.

2 The historical events and construction characteristics of the Faculty of Engineering

2.1 The design process

A long sequence of events affected both the project's design and the Faculty of Engineering site selection in the urban area. Between 1914 and 1932, there were at least four different proposals [4] for the location and the consequent distributive solutions; finally, an area of incontrovertible landscape value was chosen, at the basis of the Osservanza hill, in the vast park of Villa Cassarini (Fig.1), where the entire skyline of the city could be enjoyed to the north side [5]. Undoubtedly this was an added value to the building, so that Vaccaro himself recognized that “the location of the School is truly exceptional (...)” [6].

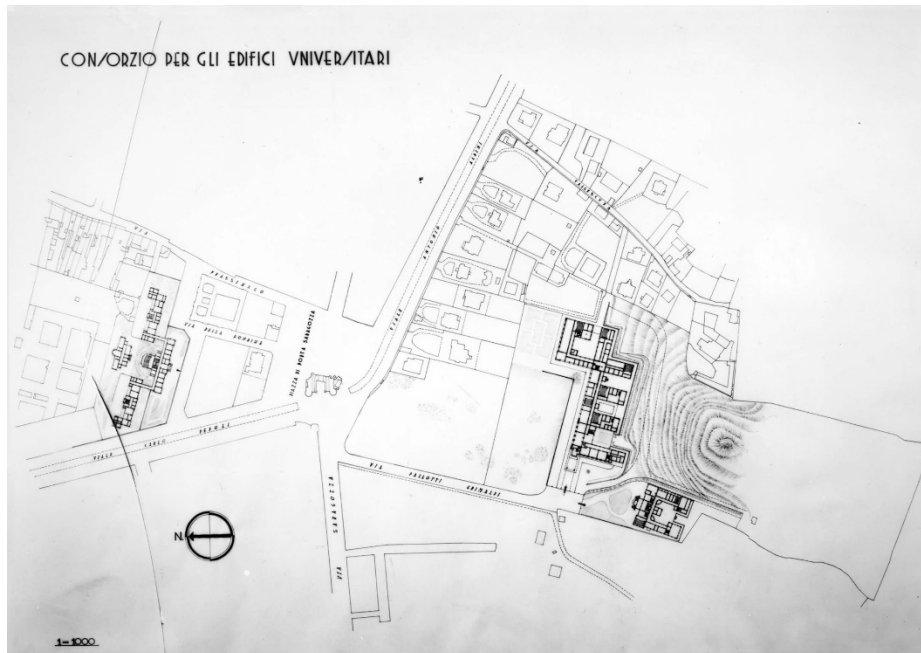


Fig. 1. Plan of the area of the park of Villa Cassarini with the building of the Faculty of Engineering. (original drawing: 021 inv. EDI 731 © ASUB archive)

The Technical Office of the Consortium for University Buildings oversaw the project regarding its internal planning, and the Giuseppe Grazzini & Figli company took care of both the structural design the construction works. Giuseppe Vaccaro was involved in the project from 1931 onwards; at his express request, he gave the building its own architectural forms, and he also participated in defining its functional and distributive scheme. We can infer this because he took this building [7] as an exemplary case (Fig.

2) to describe the procedure for representing the design process according to a functionalist approach [8].

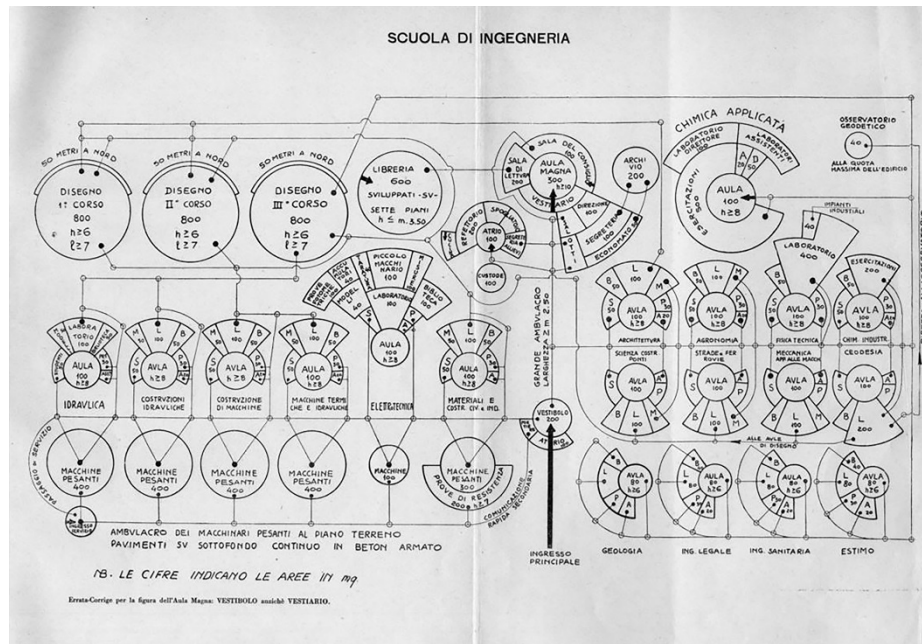


Fig. 2. Distribution scheme for the School of Engineering type extracted from "Vaccaro, G.: Schemi distributivi di Architettura" (1933). [8]

The educational and professional path of Giuseppe Vaccaro (born in Bologna on the 31st of May 1896) is crucial to comprehend his architectural point of view. After completing his classical studies, in 1916, he graduated with full marks as an architectural design professor at the Royal Institute of Fine Arts in Bologna. He continued his studies at the Architecture Section of the Royal Application School of Engineers in Bologna, where, in 1920, he graduated with full marks. Vaccaro's academic career as an assistant to Attilio Muggia, the professor of Technical Architecture and the agent of the Hennebique patent for central Italy since 1897, did not have a positive outcome. Then he devoted himself to professional activity, gaining national attention as the winner of numerous competitions: Piazza della Balduina in Rome (1923), the monuments to the Fallen of Bologna (1924), and San Giovanni in Persiceto (1925). In the late 1920s, Vaccaro was involved in major projects: The Palace of the League of Nations with Carlo Broggi and Gino Franzi (1927), the Post Office Palace in Naples with Franzi (1928 - 1929), the Ministry of Corporations in Rome with Marcello Piacentini (1927 and 1928). Vaccaro's contribution to the Faculty of Engineering project led him to acquire full awareness of the Modern style features, which reach fulfillment in his masterpiece, the Agip colony in Cesenatico. These two projects represent his style in the 1930s.

Vaccaro was commissioned to design the building during the years of his professional growth, which led him to firmly adhere to the rationalist trend and the consequent formal simplification of his works. Vaccaro began to approach the principles of a functionalist vision in these years; his reflections on the meaning and forms of Modern Architecture find a perfect match in the transformations he made to the projects being defined in these years [9].

His design accuracy made the building a turning point for the Bolognese architecture of the first half of the Twentieth century, so significant to be considered the first modernist and rationalist project in Bologna [10]. It is realized in perfect accordance with the Modern Movement's rules, as it embodies the fundamental principles of the building considered as "a mechanism" and as an expression of purity, wisdom, and knowledge.

The first documents involving the architect are dated back to 1932, when Gustavo Rizzoli, the Civil Engineering Department chief engineer, submitted the authorization request to the Building Commission for the Royal School of Engineering's new headquarters [11]. The presented project already looks very similar to the built one; there are only slight differences: the building was initially conceived as raised on a pedestal, giving it greater solemnity. This pedestal had significant repercussions on the internal distribution and volumes.

As for the façades, although the layout was already based on the coexistence of horizontal and vertical windows, we note how the distinction becomes more evident in the final project. The desire to emphasize the modern character of the building led the architect to diversify the materials in the most characterizing façades. Namely, in the library and the Lecture Hall, designing them with massive protruding pillars instead of continuous windows, he gave depth to the elevation.

Changes were made to the tower's elevation, reorganizing the openings on the north side and significantly simplifying the decorative apparatus on the access side. The first solution with an alternation of marble and brick was abandoned, in favor of bricks only, to achieve a clearer solidity and a durability image. Finally, the pool and the surrounding pavilion were eliminated and replaced by a simple but large canopy that still welcomes those coming to the building from the main entrance (Fig. 3).

The project was approved in February 1933; the construction works began in December and were completed on the 28th of October 1935. As known, this date celebrated the anniversary of the March on Rome, set to celebrate the successes of the new course of history. Many Italian public buildings were inaugurated precisely on this date as they were the concrete evidence of it. Nevertheless, the first official visit took place on the 28th of October of the following year, as evidenced by a propaganda video [12]. In the presence of Cardinal Nasalli Rocca, the effective inauguration was on the 2nd of January 1936. The video footage is extremely interesting as it emphasizes the characteristic features of the building, especially about the "modern" and "rationalist" principles, as well as the innovative features regarding the plant engineering point of view [13].



Fig. 3. Above: Perspective attached to the Building Commission's authorization request dated 1932. Below: perspective dated 1933. (composition of original drawings: Fondo Ufficio Tecnico - PUT 5635/1932 [PG 26313/1932] © ASCBo archive, 025 inv. EDI 735 © ASUB archive)

2.2 Description of the building

The study of the combination of modernity and tradition that characterizes the technical and construction aspects of the Faculty building is rooted in archival research. The Historical Archive of the Municipality of Bologna (ASCBo) holds the architectural projects subject to the authorization of the Building Commission, while the as-built project and pictures of the construction phases are available at the Historical Archive of the

University of Bologna (ASUB). The structural executive drawings and the construction site documentation are stored up at the Historical Archive of the Emilia-Romagna Region - Civil Engineering Fund (ASRER).

According to the retrieved archival documentation, the building occupies a 6.100 square meters area, parted into 3 or 4 floors blocks. The link with the context immediately appears to be one of the founding themes of the project; in fact, the layout made it possible not to compromise in any way the majestic trees of the park. The distribution scheme is organized on a complex divided into several blocks, with a representative area near the main front, a connecting corridor with laboratories and drawing rooms, and the transverse building blocks, where the Institutes were located. Each block housed a single teaching sector, equipped with its own classroom, teachers' offices, and laboratories; the latter were located on the ground floor and connected by internal stairs to the relative Institutes. The courses without laboratories were located on the upper floors, as they did not require direct access to the ground floor. Therefore, each discipline was almost independent of the others, thanks to the particular and functional layout.

The planimetric distribution, the so-called comb-like scheme, was adopted as the best solution for the rational organization of practical and theoretical activities, with the rooms' spatial autonomy for laboratories, libraries, and classrooms.

A long and straight central corridor, perpendicular to the helio-thermal axis, served as a connection between the building blocks at all levels; it gave access to the large drawing rooms, one for each course and each floor. The north-east orientation gave these rooms reduced insolation and non-invasive lighting. The classrooms were equipped with optimal window ventilation systems for the students' well-being [14].

The main entrance was located on the west front, under a large canopy, made with a reinforced concrete structure covered in pink Verona marble and gold-like metal sheets. Near the access and the double-height vestibule, there were the administrative and representative rooms, such as the management and the secretariat; the main staircase, covered in marble with a brass handrail, led to the Lecture Hall and to the Teachers' Council Room, which was also the reading room of the adjacent library. This preserved a very rich archive of 60.000 volumes, located in the 45-meter-high tower whose top was used as a geodetic observatory. Ventilation and lighting had been specifically designed for the tower's volumetric shape: ribbon windows to the north and small openings to the south ensured proper air circulation while avoiding direct insolation of the stored materials. The east wall was entirely glazed; a glass-brick façade solution allowed natural lighting in the deep stairwell for the exclusive service of the tower's archive (Fig. 4).

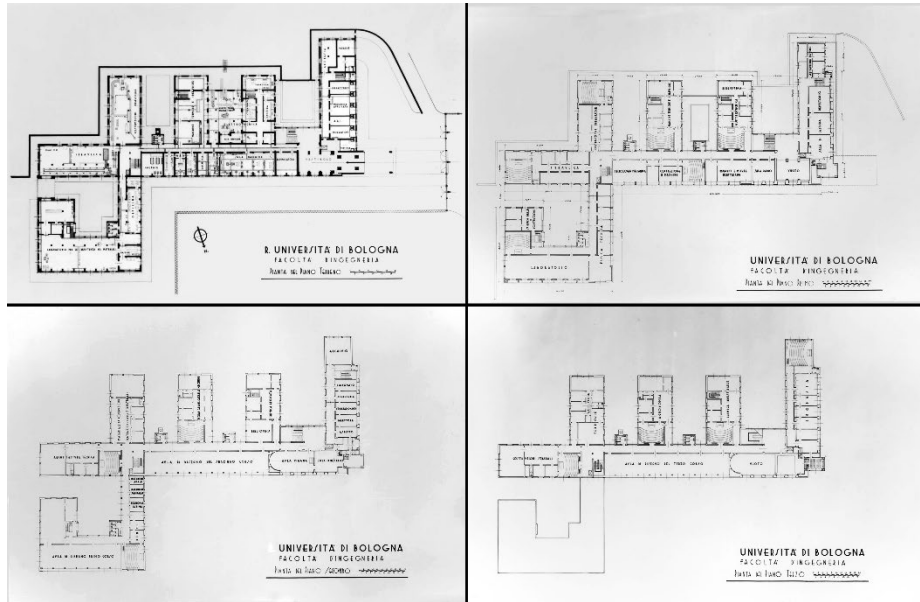


Fig. 4. Plans of the as-built project for all floors of the Faculty of Engineering in Bologna. (composition original drawing: 007 inv. EDI 718/012 inv. EDI 722/016 inv. EDI 726/018 inv. EDI728 © ASUB archive)

The architectural distribution choices were based on the fundamental principles in designing school buildings: maximum flexibility in the layouts and planimetric forms that would allow future extensions. Flexibility has undoubtedly been achieved, as the building was designed for 300 students, but now it contains a tenfold number.

2.3 The construction technique

The load-bearing framework of the building is divided into four blocks, structurally independent through expansion joints. It is entirely made of a reinforced concrete frame, with pillars at a very regular distance, generally equal to five meters; the infill walls consist of double solid brick walls, with two layers of bricks having different thicknesses depending on their location and that are separated by an air gap [15]. Although the masonry walls had no collaborative role with the reinforced concrete structure in the load-bearing concept, they assume a precise construction meaning since they were frequently raised before constructing pillars and beams. The site images (Fig. 5) clearly show the empty spaces left inside the masonry infills for the subsequent construction of the reinforced concrete structural elements, functioning as formworks for the subsequent flow [16].

From a formal point of view, the construction solution adopted for the vertical structure - which combines a resistant frame structure with solid masonry infills - allows recognizing the Italian approach to Modern construction, where the innovative reinforced concrete technique remained hidden through the external surfaces. The framed

system allowed freedom in planning interior spaces, but externally the masonry character was maintained [17]. Foundations complete the framework with beams and a massive slab of almost 190 square meters located below the tower.



Fig. 5. Pictures of the construction phases. (historical photo: Cantieri IV - 12 © ASUB archive)

Four different types of hollow brick floors were used for the horizontal elements; two of these are the typical solutions of the 1930s for “air chamber” floors, consisting of the assembly of brick blocks specially shaped to cover large spans and withstand very high loads. These are the Stimip floors by the RDB company and the Bidelta floors by the Frazzi company. They were conceptually similar but had a different conformation of the brick blocks: the Bidelta had a characteristic narrowing at the ends to increase the structural section of the ribs in the most shear stressed position, and was completed with an upper concrete slab, which was instead replaced by a collaborating brick slab in the Stimip floor [18]. In addition to these two innovative products, which were used for large spans and where particular thermal and acoustic comfort was required, there were more traditional solutions, such as the Excelsior floor (also produced by RDB) and the Brunori floor, especially in the corridors and in the small span rooms.

The building had the most advanced technological and plant equipment; innovation is also tangible in the finishing works. For example, the façades were entirely covered with Terranova plaster, a special plaster patented at the end of the Nineteenth century in Austria and produced in Italy since 1932. It was characterized by pigmentation during the premix production that gave it particular resistance to atmospheric agents, thanks to its impermeability, which was achieved by its specific quartz-based composition [19].

In the internal representative areas, there were thin stone coatings, according to the typical practice of the 1930s of using stone as a reference to classical architecture, conveying an idea of richness, inalterability over time, durability, and strength.

The firm adherence to the Modern style in the façade's formal composition does not neglect the local construction tradition. After all, by Vaccaro's own admission, he was looking for simple and severe modernity, which was nevertheless linked to the spirit of the Bolognese architectural tradition, both in the use of materials and in the proportions. The treatment of the exposed basements and the tower's presence can be traced back to this concept (Fig. 6).



Fig. 6. The Faculty of Engineering at the time of its inauguration. (composition of historical photo: Ufficio del Genio civile di Bologna, Busta n. 49, Titolo 3, Classe B, Posizione 28 © ASRER archive).

Technological innovation is the distinctive feature of the north-east façade, where the teaching rooms were located, overlooking the park; the reinforced concrete structural frame made it possible to separate the load-bearing structure from the façade organization, allowing the architect to create long ribbon windows. These combined the compositional requirements of the façade and the search for the best exposure of the classrooms, in a close relationship with the surrounding environment: the use of *ferro-finestra*, a specially patented iron fixture designed to reduce the opaque part compared to the glazed one, made it possible to create an uninterrupted transparent surface of almost 50 meters. These fixtures were produced in Bologna by the Curti S.A. company, a world leader in the sector. The third floor's drawing-room was equipped with a particular fixture that could be entirely mechanically opened, also patented by the Curti S.A., which had a hinged opening for a length of 35 meters [20]. The large glazed surfaces give the building a horizontal rhythm, interrupted only by the verticality of the representative areas near the main entrance, which culminates in the tower as a reference to

historic Bologna. The contrast between horizontal and vertical lines is not a mere architectural expedient but reflects the functions of the various portions; a tangible architecture is obtained, thanks to the balance between the static nature given by the solid brick and plaster masses and the dynamism proper of the articulation of the plans and the façades.

3 The library tower

3.1 The towers in early Twentieth century Italian architecture

The modern character of the Faculty of Engineering building is manifested through a diversity of typical elements of the '30s. One of their highest expressions is the book storage tower, near the main entrance of the building, that assumes a double value: on the one hand, as a symbolic element for its period of construction, on the other hand, for the local tradition of tower buildings.

The origin of towers in architecture can be dated back to ancient times; in almost all cultures, men have built towers to strive to the sky, fulfill their curiosity, and break human limits. Thanks to the constant advancement of technical and construction knowledge, towers have become the symbol of spiritual aspiration to heaven.

The symbolic meaning of towers also recalls another character of the human soul, which led men to outstanding construction: the yearning for power, fame and wealth, sovereignty, and command. Along with the spiritual vocation, the tower embodies the desire for power and greatness, first enriching princely castles and public buildings, such as the town halls, until it became an expression of a new form of power: the fascist dictatorial regime [21].

The medieval towers are also a symbol that undeniably recalls Bologna's local history, identifying the city as the "City of Towers". In addition to the most celebrated Garisenda and Asinelli, built at the end of the Eleventh century, almost a hundred other towers were built from the Eleventh to the Thirteenth Century, with offensive-defensive function and a political affirmation meaning [22, 23].

The tower consolidates its peculiar meaning of a totemic and allegoric object in the rationalist architecture; in the first half of the XX century, no other State politically invested in public architecture as the Fascist regime did in Italy. Architecture became bound to politics and a government instrument to obtain the masses' consent as a formidable means to exhibit and consolidate power [24]. Since towers are recognizable even from a great distance and able to symbolize the Fascism presence in the various cities' contexts, they acquired the status of a representative command element that frequently appears in Italian rationalist architecture.

Therefore, towers are built in central strategic positions or next to public or civil buildings, giving them a more significant monumentality character. Fascist buildings, such as the "Case del Fascio", "Gruppi Rionali Fascisti", Municipalities or Government Palaces, without a tower, would have been simple buildings for public functions and would not have represented the greatness and superiority of the regime, especially in small and medium-sized urban centers [26]. Towers were also often associated with

educational and cultural buildings such as schools, universities, and at the service of the “Opera Nazionale Balilla”, becoming the visible symbol of railway stations and post offices, assessing once again the propaganda goal [27]. When erected near stadiums and public sporting fields, they emphasized the party’s interest in physical activity, perceived as the ability to define a national identity, while giving these works the magnificence that characterized them in ancient times (Fig. 7)0.

In the 1920s, between the two World Wars, the tower was an image of progress and technological advancement worldwide, whereas, in Italy, it represented a potent symbol of dictatorial political power [28].



Fig. 7. Other rationalist towers of the early ‘1930s: Casa del Fascio in Mussolinia (Arborea - OR); Palazzo Littorio in Montevarchi (AR); Torre Littoria (TO); Casa del Fascio in Predappio (FC); Palazzo di Città (PE) (composition of public domain photos: all pictures retrieved from Wikipedia under CC BY-SA 2.0)

3.2 Construction features of the library tower of the Faculty of Engineering

The tower of the Faculty of Engineering of Bologna represents a distinctive element of the entire complex; it is an intentional reference to the Bolognese architectural tradition and a peculiar symbol of Italian rationalist architecture. However, it is not the umpteenth re-proposal of the regime’s most characteristic architecture but the result of a

design choice that meets specific functional requirements, which transcend the purely formal meanings.

The desire to make the tower an autonomous figurative entity probably stems from the architect Giuseppe Vaccaro's idea, even if it is already recognizable in other previous proposals. It was not designed to fulfill only a formal architectural aim but was conceived as integrated with its function, namely the Faculty library's containment. According to Vaccaro's idea, keeping books inside a vertically developed space would have made it easier for librarians to move heavy books using a dedicated lift instead of making frequent and tiring book transfers through long horizontal corridors.

The tower envelope is realized by an exposed brick texture, which recalls the building's base, contrasting with the other parts of the main façade s in the "Terranova" plaster.

Although it looks like a volume with simple geometry, the tower hides a complex construction and structural system. Up to the third floor, it is integrated into the building atrium and stairwell, which contain its structure and organization. By being inserted into the building's structure, the tower becomes difficult to perceive when entering the main entrance. However, although well integrated, the tower and the Faculty building structure are two distinct blocks, designed independently and separated through expansion joints of about 5 centimeters.

The tower's foundation consists of a vast slab extended for about 190 square meters, designed to transfer to the ground a load of less than 2 kg/m^2 . As far as the elevation is concerned, the tower consists of a reinforced concrete frame system and intermediate hollow-brick floors. According to A. Giannelli's formulas, the structure was calculated with the 9-story frame method derived from the 4 and 6 moments equations. Structural calculations also considered the wind action, the thermal action, and the conglomerate shrinkage [29].

In correspondence with the building's main entrance, the four pillars bearing the tower structure are exposed. They present an evident peculiarity because of their original design: a 12 cm thick strengthening in reinforced concrete is hooping each pillar, whose structural dimensions were 130 x 90 cm. So, the pillars, including the reinforcement, reach the total size of 154 x 114 cm at their base. The pillar reinforcement has a different arrangement of the rebars between its bottom and its top, i.e., 34 longitudinal rebars of 25 mm at the base and 24 of the same diameters at the top. It is not clear what function this reinforcement had, but it seems to be twofold: on the one hand, it contained the compression forces acting on the supporting pillar; on the other hand, it was used to create a fastening system for the marble cladding, consisting of pink travertine slabs, adequately fixed to the reinforcement with stainless metal bolts.

The pillars on the second floor also have a reinforced concrete strengthening system. In this case, it is made by L-shaped concrete columns in adherence to the long side of the pillar and oriented inwards, adding a sufficient size to support the upper floors pillars.

The four pillars progressively reduce their size along the tower's whole elevation; the last pillars at the top change their geometry, from a rectangular section to a square area of 60 x 60 cm. Each pillar is reinforced with smooth rebars with a diameter of 30 mm and iron brackets Ø8 every 25 cm. Each pillar is connected to the other pillars through

rectangular cross-section beams 90 cm high and 60 cm wide on the frame's longest side. On the shorter side of the frame, the beam cross-section is only 90 cm high and 30 cm wide. At the floor level inside the Faculty building, there are also other smaller pillars and a complex system of beams and hollow brick floors that constitute the direct connection between the tower and the building block without creating any kind of spatial gap.

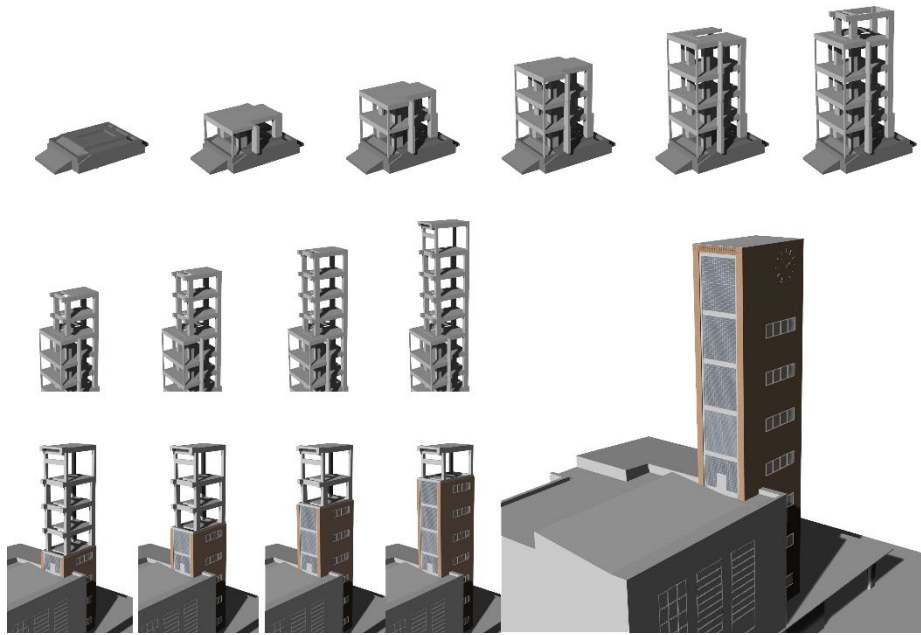


Fig. 8 Development of the tower in its elevation. (graphic elaboration by Alessandra Amadei)

The tower shape emerges from the Faculty building shape from the fourth floor, and its frame is systematically repeated up to the roof, except for the size of the pillars that decreases, as said before, following various tower levels (Fig. 8).

The infill wall system on the towers' sides is realized with a solid brick masonry having one brick thickness, supported by an edge beam made slightly overhanging the perimeter beams.

On the eastern façade, instead, the infill wall solution was different and turned out to be the system's most distinctive trait, both in structural and architectural terms. The architect's goal was to create a large opening through a glass-brick wall that would illuminate the books' deposit without creating the traditional delimitation of each level. Therefore, large reinforced concrete cantilevers overhang from the tower frame at each floor on the east side to bear the beams supporting the glass brick façade. Thanks to this particular structural scheme, a continuous internal void is created for the whole tower height, vertically crossed by the iron staircase, while creating a continuous translucent external façade from the fourth to the ninth level. This technical solution responded to

functional needs and gave the tower a strong architectural character, making it an example of modernity and symbolically a sort of lighthouse on top of the hill.

During World War II, however, the strong explosions due to the bombardments caused irreparable damage to the glass brick wall, which was then demolished and replaced with the actual wall, which preserves only a few original glass bricks inserts (Fig. 9).

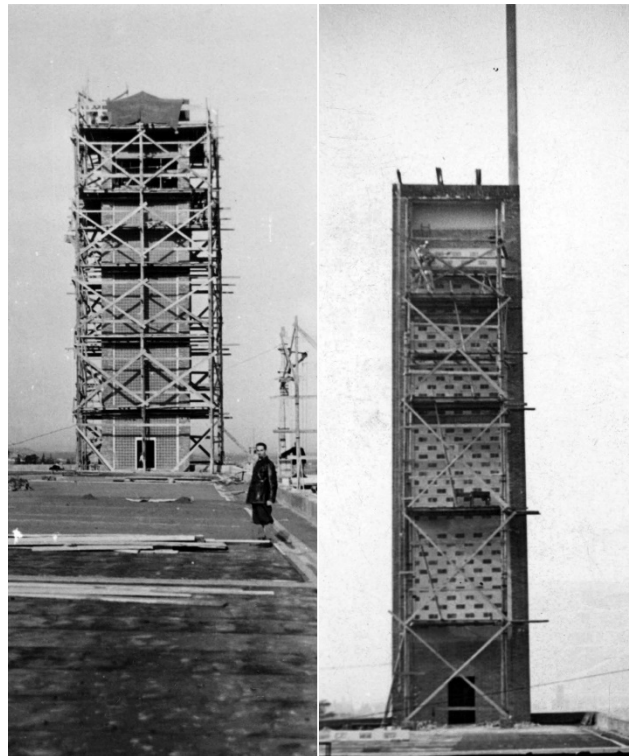


Fig. 9. Comparison between the solutions for the construction of the east façade in the original project and the reconstruction project. (composition of historical photo: Cantieri II - 24/Cantieri II - 006 © ASUB archive)

3.3 The east façade of the tower of the Faculty of Engineering

The library tower eastern façade, opposite the main entrance, is certainly the most original, and it has never been investigated sufficiently to identify the construction methods and materials.

Giuseppe Vaccaro's project foresaw, in correspondence with the eastern elevation, a large glass brick façade, divided into five sectors, which let external light illuminate the entire metal staircase inside. Each glass-brick field rested directly on its supporting beam. Thanks to the reinforced concrete structure with overhanging cantilevers, each

glass-brick field was not connected to the tower's core structure, creating a unique design from the fourth to the ninth floor (Fig. 10).

The glass-brick used for the original façade is a “Nevada” brick-tile from the “Fabbrica pisana di specchi e lastre colate di vetro”, Italian dealer of mirrors and chemical products “Saint Gobain Chauny&Cirey”. The “Nevada” ultra-clear glass tile brick, developed after long studies and tests, was able to meet the requirements of great transparency, close laying, excellent light diffusion, robustness, brilliant effect, good resistance to atmospheric effects, and transmission of cold and noise sought by the designer [30].

The chosen Nevada tile was type A.I. 204 of cm. 20 x 20 and height cm. 4. The installation instructions taken from the Saint Gobain Chauny&Cirey manual suggested using concrete as a binder for the external façade and arranging a reinforcement grid with Ø5 rebars in the horizontal and vertical directions for large walls. It was always necessary to construct a support strip about every 3 m to avoid distortions in the glass-brick wall due to the load-bearing structure's deformation.

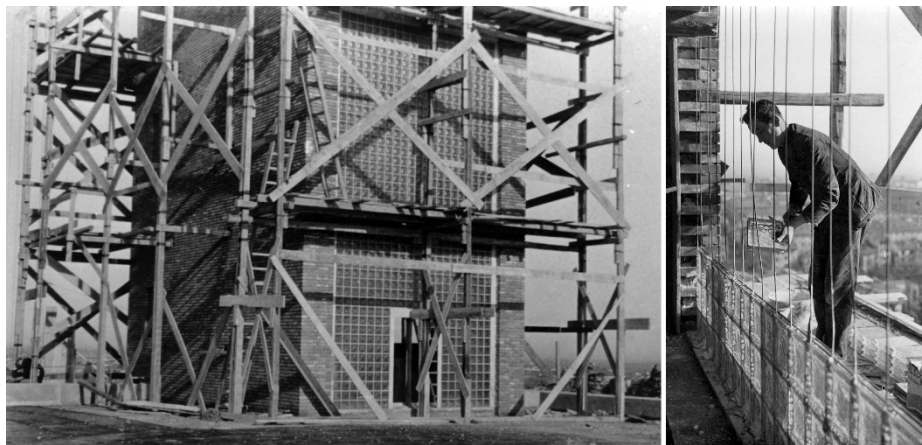


Fig. 10. Construction phases of the original glass-brick façade. (composition of historical photo: Cantieri II - 22/Cantieri II - 001 © ASUB archive)

The current façade of the east elevation of the tower, as already pointed out, does not correspond to the technical and architectural solution planned in 1935 by Giuseppe Vaccaro and is one of the most significant modifications that the entire complex has suffered after the Second World War. During the air raid of the 22nd of March 1944, a giant gauge bomb exploded close to the outer wall of the eastern building block. Severe structural damages were caused to the building, and almost all the glasses, crystals, and fixtures were broken. The ancient glass-brick façade was also inevitably affected by the explosion air blast and suffered considerable damage that compromised its preservation and restoration.

Although no pictures were found documenting the damage level to the eastern façade after the air bombing, it was entirely demolished and rebuilt in other ways, considering

it the quickest and most effective solution. The reconstruction was carried out in 1948, according to a formally and technologically different solution from the original one. This new configuration was suitable for rapid installation and proved to be a more economical solution.

From the outside, it appears like an uninterrupted façade, characterized by a geometric design coming from the alternating arrangement of glass-bricks and solid blocks. From the inside, it reveals its remarkable peculiarity: a plastered surface with horizontal ribs, as wide as the entire façade, that space out glass-bricks inserts. At first glance, they seem regular, but on closer inspection, they reveal significant differences in shape and section.

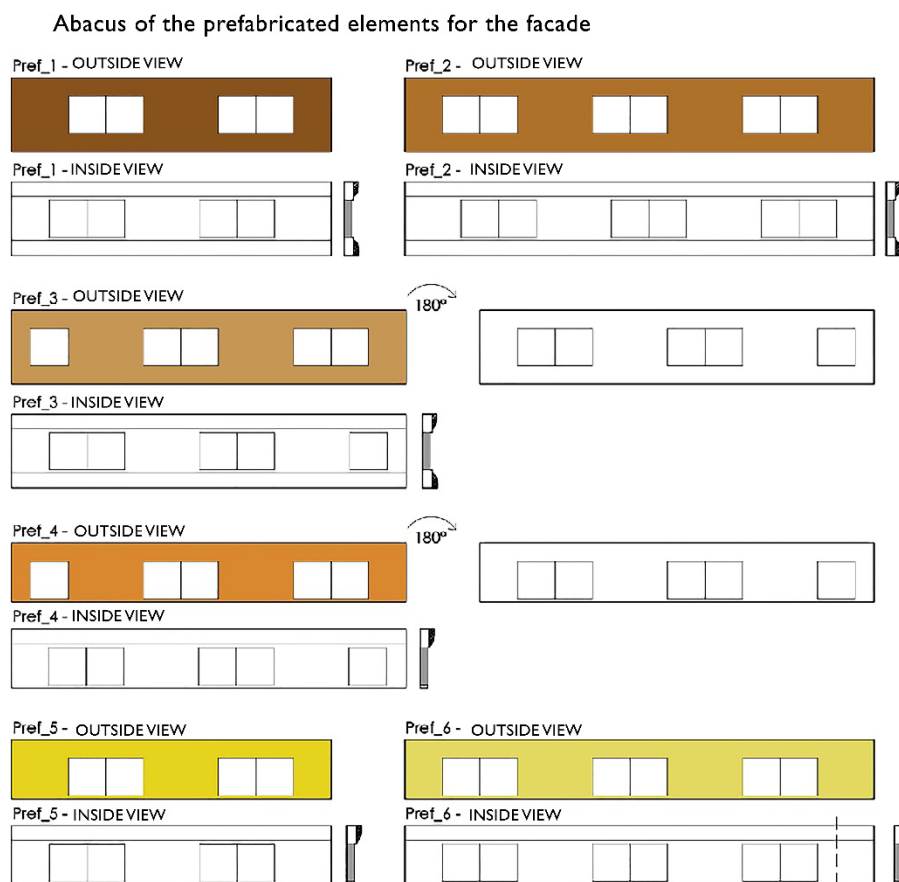


Fig. 11. Abacus of prefabricated blocks. (graphic elaboration by Alessandra Amadei)

Thanks to the archival documents, the execution appraisals, and the priced bill of quantities, it was possible to demonstrate that the current façade is made of prefabricated reinforced concrete elements. The archival sources report as follows: “reconstruction of

the glass wall with reinforced precast panes and finished in travertine and with glass-bricks “Nevada” tiles of the size of cm. 20x20x4” [31].

Therefore, the external surface is treated like “artificial travertine”, engraved with false grout joints to imitate marble blocks’ joints. Their geometric definition and their placing within the façade are thus one of the most interesting themes of the building’s cognitive process and an aspect that has not been thoroughly investigated until now.

3.4 The role of direct investigations

The most useful tool for identifying the geometrical arrangement of the prefabricated blocks was the crack pattern on the façade. A careful analysis of the degradation state highlighted cracks following a relatively regular and repetitive mutual pattern between inside and outside. Cracks are located near the horizontal and vertical joints within the prefabricated blocks constituting the wall.

Analyzing the frequent horizontal cracks at the centerline of the ribs and observing some historical photographs, it was possible to define one of the prefabricated block dimensions, i.e., a height equal to the distance between two successive ribs. Instead, its width was identified by the recurrent vertical cracks both inside and outside the façade, showing a typical staggered joint arrangement. The final geometrical and structural characterization was possible by the performed tests on-site. The drilling samples confirmed that the façade is made of prefabricated concrete blocks with coherent dimensions of internal and external cracks. Three types of prefabricated blocks have been identified, still containing coupled glass bricks, aligned to the outer edge of the façade (Fig. 11).

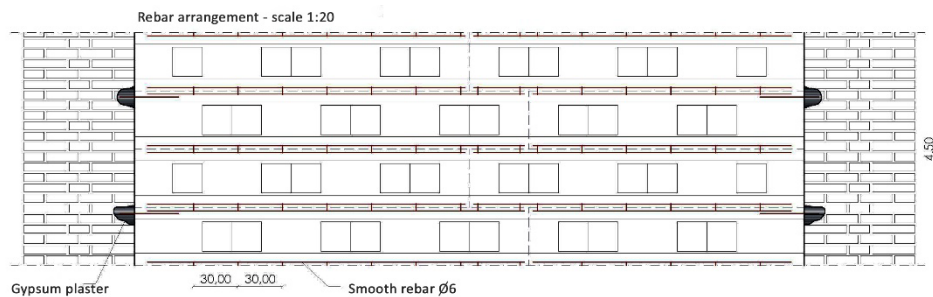


Fig. 12. Outlining of the reinforcement of prefabricated blocks. (graphic elaboration by Alessandra Amadei)



Fig. 13. Tests performed on the internal façade. (authors' original photos)

Each prefabricated block has a rectangular section with a round swelling at the top and bottom, where the smooth iron reinforcing rebars are located. Therefore, the swelling allows the reinforcement arrangement and facilitates the installation by increasing the contact surface between one block and the other when overlapping. In correspondence of the ribs, which owe their rounded and irregular shape to a plaster coating, the horizontal reinforcements are arranged. These are connected from one block to the other through the steel bindings (Fig. 12).

The smooth horizontal rebar is interrupted at the end of the prefabricated block, and there is no overlapping of reinforcement between adjacent blocks: this evidence indicates the positioning of the reinforcement during prefabrication and not on site. On the contrary, the bindings that connect reinforcements of two surmounting different prefabricated elements show a different conception. It can be assumed that during the blocks production phase, they have been shaped, leaving proper interruptions that kept the reinforcement rebars visible to perform the bindings, or that they have been locally demolished in correspondence of the joints during site construction.

There are no vertical rebars, and from what emerged from the tests, it also seems evident that there is often no connecting mortar in correspondence of the joints, or its presence is minimal (Fig. 13).

The glass-bricks have been inserted inside the prefabricated blocks after their construction; they are 470 in total, 320 are new ones, and 150 re-used from the original “Nevada” tiles. Therefore, the prefabricated block’s entire thickness is slightly larger than a single glass brick, in total, about 5 centimeters.

The last aspect of the investigation is the connection between the eastern façade and the brick masonry on its sides. There are two hollow brick walls directly connected to the external cladding of the infill walls on top of the reinforced concrete cantilevers. The prefabricated blocks are inserted into this masonry, which is partially chamfered, and bonded to it through the addition of plaster and small hook-shaped reinforcements that cross the two brick headers.

The thorough historical and technical analysis of the eastern façade was also fundamental for understanding the causes that led to its degradation. The most evident phenomena are the horizontal and vertical cracks in the façade, which affect the entire surface. As already said, they are precisely located at the junctions between blocks, and the chromatic alterations, which are evident on the internal plaster, are due to the unwanted runoff of rainwater. In addition to these cracks, the fissures on glass bricks and their poor water tightness installation also increase rainwater penetration.

More significant fissures can be observed between two adjacent glass bricks and smaller fissures between them and the reinforced concrete structure of the prefabricated blocks. Finally, also spalling and small fractures on the re-used glass bricks are visible.

3.5 Analysis of the safety conditions of the façade through its survey

Together with its construction characteristics and preservation state, the eastern façade’s transformation phases have suggested performing verification of its verticality.

For this purpose, a 3D point cloud was realized through a survey campaign carried out with a terrestrial laser scanner (TLS) followed by the different scans’ processing in the back office. The equipment consisted of a FARO CAM2 Focus 3D phase-shift terrestrial laser scanner, and the alignment of the scans was made with the FARO SCENE software (version 2019.2) developed by FARO Technologies, Inc. [32]. The result is a faithful model to the real building, which avoids the possible and inevitable simplifications that would have arisen during a manual survey. The overall survey of the entire historical complex of the Faculty of Engineering counts 188 scans resulting in a 2 billion

dot point cloud. About 50 scans were made for the library tower staircase, plus a specific campaign for the external walls, the roof, and the eastern façade counting another 25 scans (Fig. 14).



Fig. 14. Screenshot with the entire point cloud model of the Faculty of Engineering of Bologna in FARO SCENE software. (authors' digital elaboration)

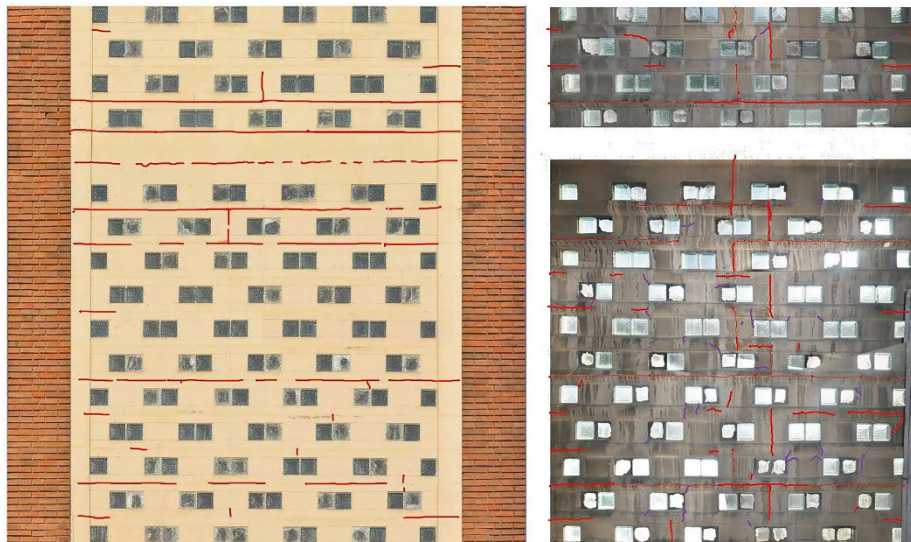


Fig. 15. Internal and external photomosaic of the eastern façade tower with highlighted fissures and cracks phenomena. (graphic elaboration by Alessandra Amadei)

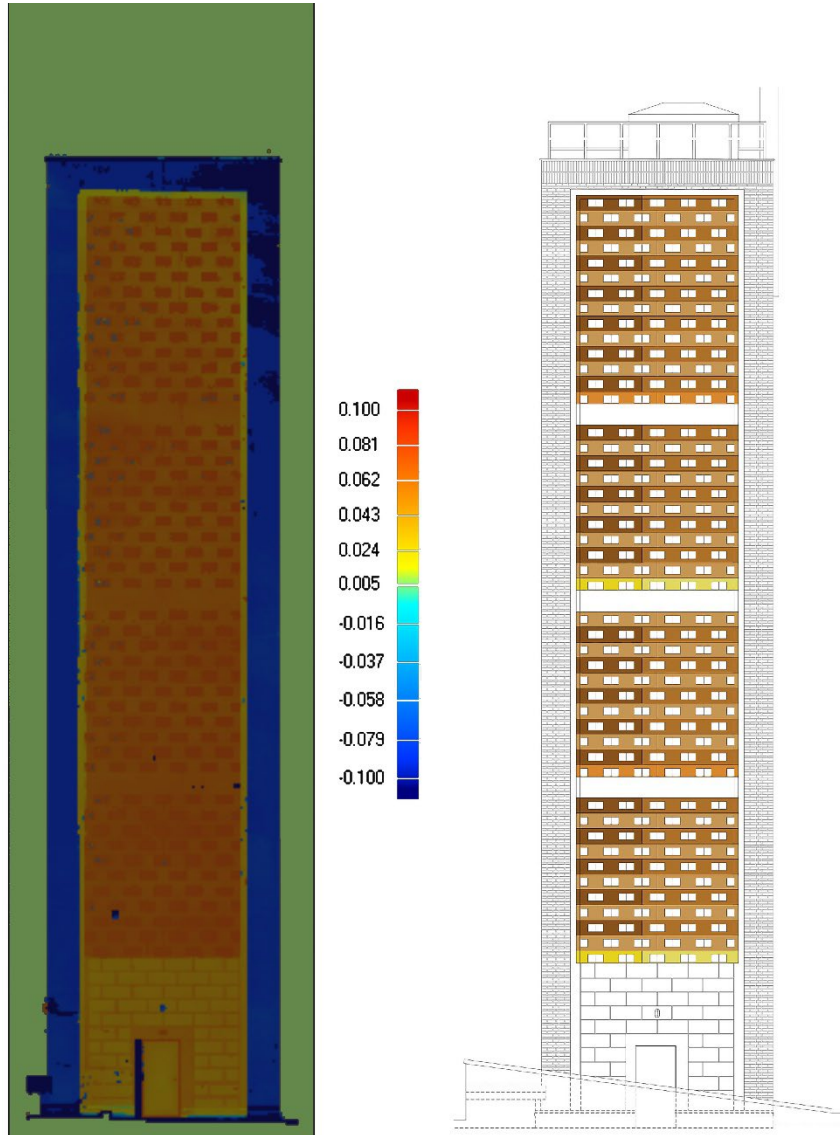


Fig. 16. On the left, a geometric analysis performed with Geomagic Control software: the different colors represent each point of the model's distance from a perfectly vertical reference plane. The point distribution regularity is evident. On the right: reconstruction of the shape and arrangement of the façade's prefabricated blocks. (graphic elaboration by Alessandra Amadei)

The laser scanner survey was combined with a manual survey of the portions unreachable by the scanner and a detailed photographic campaign, aided by a Mavic Pro drone. The pictures were used for the digital rendering of a photogrammetric model in the form of a photomosaic. Especially the photographs taken by the drone have allowed

observing more closely the actual state of conservation of the exterior façades, focusing on the highest portions not accessible by a manually-operated camera or the scanner (Fig. 15).

The eastern façade was segmented within the point cloud and imported into the software Geomagic Control To perform a geometric analysis. The goal was to identify any evident deformation of the façade both locally and globally, comparing the façade 3D model with a vertical plane and evaluating each point of the model's distance from that plane (Fig. 16). Through a color graphic rendering, the software shows these distances and highlights any anomalies.

The analysis has been performed several times by slightly changing the software settings to increase or progressively decrease the analysis level of detail. The results reveal the absence of significant anomalies. The façade, as a whole, is free of substantial deformations, and each of its parts at different heights is nearly parallel to the adopted vertical reference plane. Therefore, it does not present significant overhang phenomena that would have been highlighted in the figure with marked differences in coloring within the same "layer" of the façade. Although not going into the numerical analysis, we can see a significant deviation in the upper part, which does not affect the restored glass-brick elevation. It is attributable to the local deterioration of the bricks rather than an actual overturning of the façade.

While not excluding the need for more accurate studies of the state of conservation of the library tower, the results obtained do not highlight significant critical issues that could forewarn possible damage mechanisms [33].

4 Conclusions

In the classical and univocally shared meaning of Modern architecture, Modernism was born when the construction activity was attracted by the attempt to improve the world that the industrial revolution was transforming by relying on the possibility of participation and planning [34]. Through the various architectural trends that run through the Twentieth century, first in Europe, then in Italy, scientific and technological progress were the pivots to base innovation.

The technological field advancements took tangible form in realizing significant civil engineering works and constructing vast buildings, often based on the principles of concreteness, economy, and functionality. This could happen thanks to designers coming from Engineering Schools, who perfected construction systems and design calculations employing new materials, such as cast iron, steel, reinforced concrete, and glass. Modern engineering constructions helped to recreate a close continuity between architectural form and structure, although the integration between architecture and technology struggled to impose itself on the dominant historicism of the time, at least in the early years.

Therefore, studying and analyzing architecture works pertaining to the Modern period is necessarily complementary to studying and analyzing their construction characteristics and building construction methods, relevant areas for the History of Construction. The frequent problem affecting Modern architecture is its conservation, and this imposes a profound reflection on methods and criteria to be adopted to find a balance

between preserving an identity character and compliance with the current demanding regulatory framework.

Nowadays, understanding the meanings of a historic building and its material characteristics is essential to ensure adequate preservation actions, having to face the transformation processes that these buildings have undergone over time, often disrespectful of the original architectural conception, with their service extension life use. Therefore, the ever-increasing knowledge of these constructions is a starting point to undertake conscious and sensible interventions. Today, many technological tools allow the integration of advanced surveying and simulation techniques, which can provide innovative and fundamental results for a real understanding of the state of conservation and the transformative processes of a historical heritage building when combined with targeted archival research.

Archival References

Figures 1, 3 (below), 4 are kept at the Historical Archive of the University of Bologna (ASUB) and are part of the “Collezione fotografica delle lastre edilizia universitaria, Facoltà di Ingegneria”: 021 inv. EDI 731; 025 inv. EDI 735; 007 inv. EDI 718; 012 inv. EDI 722; 016 inv. EDI 726; 018 inv. EDI728. Figures 5, 9, 10 are kept in the same archive and are part of the “Collezione fotografica dei positivi edilizia universitari, Facoltà di Ingegneria”: Cantieri IV - 12; Cantieri II - 24; Cantieri II - 006; Cantieri II - 22; Cantieri II - 001. Alma Mater Studiorum - University of Bologna, University Library of Bologna - Historical Archive has granted the reproduction of the images and any further reproduction is forbidden.

Figure 3 (above) is kept Historical Archive of the Municipality of Bologna (ASCBo) in the “Fondo Ufficio Tecnico” - PUT 5635/1932 [PG 26313/1932]. Historical Archive of the Municipality of Bologna has granted the reproduction of the images and any further reproduction is forbidden.

Figure 6 is a composition of historical photographs preserved in the Historical Archive of the Emilia-Romagna Region (ASRER) in the Fund: “Ufficio del Genio civile di Bologna -Busta n. 49, Titolo 3, Classe B - Opere di edilizia statale. Sezione staccata del Genio civile per l’Università di Bologna - Posizione 28 Lavori di ripristi-no dell’edificio sede della Facoltà d’Ingegneria dell’Università di Bologna”. The pictures are by Anonymous author (1936 -1939) and depict: Entrance (Viale Risorgimento), South Front, North Front, West Front. The Historical Archive of Emilia-Romagna has granted the reproduction of the images and any further reproduction is forbidden.

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