The church of Longuelo designed by Pino Pizzigoni. An unknown example of outstanding structure.

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Abstract
This paper presents a critical study of the church of Longuelo, Italy, designed in 1966 by Giuseppe (Pino) Pizzigoni (1901–1967), an Italian architect who lived and worked in the city of Bergamo. He began his studies on shell structures in the Fifties and many of his buildings show outstanding skills in conceiving and handling complex structures. The church is one of his most interesting works: it is divided in four identical free parts, each composed by four shells joined by a fifth one, supported by twenty one bars which realize an statically-determinate spatial frame resulting in an outstanding inner space.

Keywords: historical buildings, church of Longuelo, Pino Pizzigoni, space frame, thin shells, hyperbolic paraboloids, Möbius Ring.

Fig. 1 a, b: inside the Church of Longuelo: main entrance [10] and side [9] – 210bis

1. Introduction

All during the XX Century, several Italian architects devoted their efforts in finding a synergy between structure and formal character, economically reasonable while rich of new architectural opportunities. Among the most notable there are personalities like Pier Luigi Nervi, Luigi Moretti and Sergio Musmeci, but also a lot of almost unheard-of architects, whose works are of utter interest. Here a very singular building of one of these designers, namely Pino Pizzigoni, is presented: the church of Longuelo. The main information related to this building are to be found directly in his archive, located in the public library of Bergamo "Angelo Mai [9], from his own sketches and written records, which often are all but clear and marked by consistency.

The second section describes the multifaceted personality of Pizzigoni, with a special attention to the last years of his life. In the third one we present an overview of the church to understand its genesis and evolution. The fourth section elaborates on the structural behaviour of the church: as the description by the architect are often confused, different suggestions and considerations about built structure are pieced together. Finally, before the conclusion section, the fifth one looks at the real church, its actual state and its aging.

2. Pino Pizzigoni architect and engineer

Pizzigoni was born in Bergamo (Italy) in 1901, where he lived, worked for all his life and died in 1967. He studied Architecture at Politecnico di Milano since 1918 with some of the most notable Italian architects of the XX Century, like Terragni, Bottoni, Figini and Pollini. He graduated in 1924 with Gaetano Moretti as tutor, and in 1927 he designed and realized his first major project, his father's house: the building immediately gained press attention, spreading architectural discussions about formal languages and monumentality. Just then the main cultural debating was about the possibility for the Italian Rationalism to become the distinguishing style of the Fascism, but Pizzigoni never involve himself, nor became member of any political party. Quite neglected by histories of architecture, he is usually, and grossly, described as a post-rationalist architect. This is due to the duality of Pizzigoni's works, the most part of which are quite traditional, even if often high-grade building; on the other hand he was a dreamer, in search of true Art and Architecture, with his experimentation and projects supported by deep though.

2.1. Experimentation with spatial structures

After the second World War, Pizzigoni dedicated his interests in new structural typologies and, following the rising 'philosophy of structures', experimented with thin concrete shells in a field of his own property (Zandobbio, Italy). Starting from this period, in several projects for buildings as well as furniture, he approached design as an experimentation with shells and spatial structures: he realized hyperbolic paraboloids for instance as roof structures for stables of his own property in Zandobbio (1956-1960), for a Nursery School in Monterosso (1965), for a pigsties for a cheese factory in Torrepallavicina (1960-1964) [10], as well as in other buildings. Among his interests there were also reciprocal structures, which he experimented in several tables and chairs (Fig. 2).

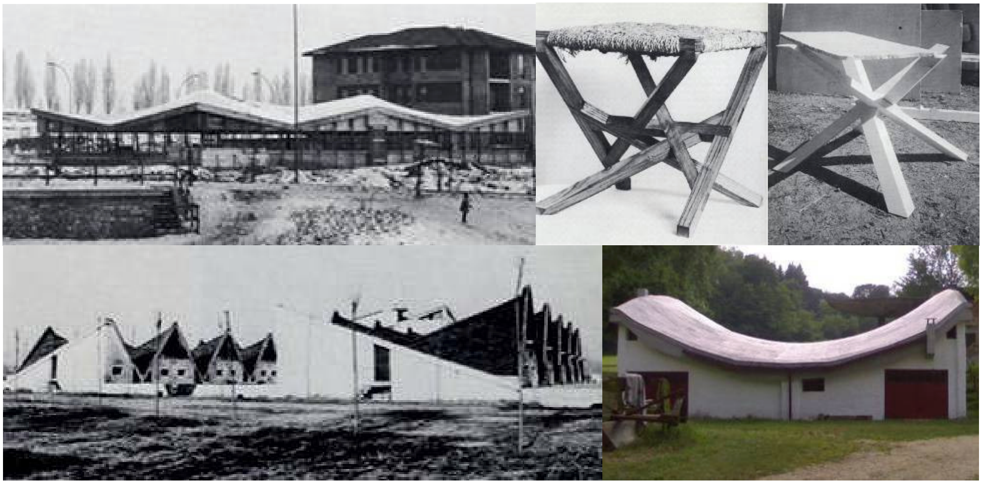

Fig. 2 a, b, c, d: Nursery School, Monterosso [10]. Reciprocal table and chair ([9] – N). Pigsties for a cheese factory, Torrepallavicina [10]. Experimental roof, Zandobbio.

However, it is important to spotlight that these experimentations always concern the possibility to obtain interesting spatial effects of the shape or to manage the light in unusual ways with a very limited cost: the financial and building facets were studied for the most, without any experimentation on the typology or the use of spaces.

3. The project of the Church of Longuelo

The church of Longuelo, whose commission dates back to 1960 and which is devoted to Maria Santissima Immacolata, is the last main building by Pino Pizzigoni (Fig. 3 a, b).

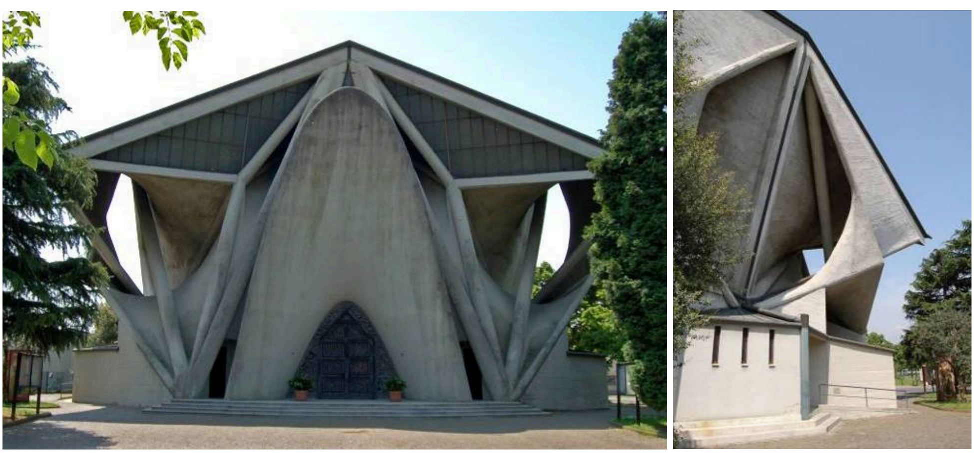

Fig. 3 a, b: outside the church, front and side.

The project dating 1961, the building was finished in 1965 and anointed in 1966: it is maybe the most considerable work by the architect, representing the summa of his experimentations about shells, taken on all during the last twenties of his activity.

3.1. Cultural approach to the project

It was not the first time that Pino Pizzigoni dealt with the theme of church and chapel, of which he designed a dozen projects, the most notable being maybe the 1954 International Competition for the Cemetery Church of Bergamo (Fig. 4). Both churches present a traditional plan composed by four symmetrical parts enriched by a complex covering.

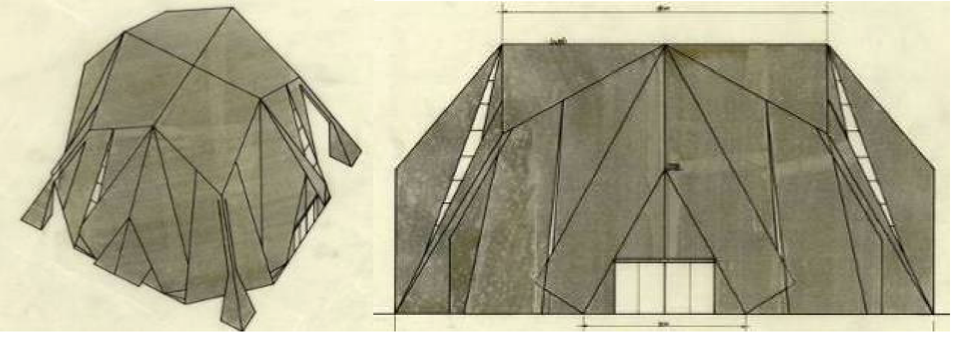

Fig. 4: project for the Competition for the New Cemetery Church of Bergamo [9] – B-100

It is not so surprising that the projects of the church starts with a division of the plan in four identical parts, organized in a very unoriginal way, and goes on with the formal inquiry of only one quarter. Pizzigoni himself, in descriptive reportings ([9] – A-210, 5-11), claims that the core of the project, the one which will decide its affiliation to the world of the true Art instead of the one of mere Buildings, should be the possibility to recognize in the final shape the action of will power, the role of the light as sculptress, and the unitary formal conception of the vaults. By Pizzigoni, it is the will power only that can lead to artistic edges, linking the world of sciences and technical cultures with the one of arts, and the rational power of predictive calculation with the expressive strength of formal suggestions.

3.2. Concepts leading the project

Since the first sketches, dating 1961, it is clear that, all during the design process, three were the main suggestions: the use of hypar shells, the Möbius Ring and the metaphorical, biblical concept of the Tent, pitched by God, as described by The Gospel of John.

It is Pizzigoni himself that claims as references of his knowledge about hypars a number of foreign text ([9] – A-210, 5-11), like those of S. Timoshenko [11][12], V.Z. Vlasov [13], F. Aimond [1][2], and V.V. Novozhilov [8]. From these texts, and from further notions by Issenmann Pilarski [7], he began to imagine a sequences of concrete shells whose shape defined a single room. Pizzigoni firstly decided to divide the church in four identical parts, then began to study the structure of only a quarter by combining hypar shells (fig. 5).

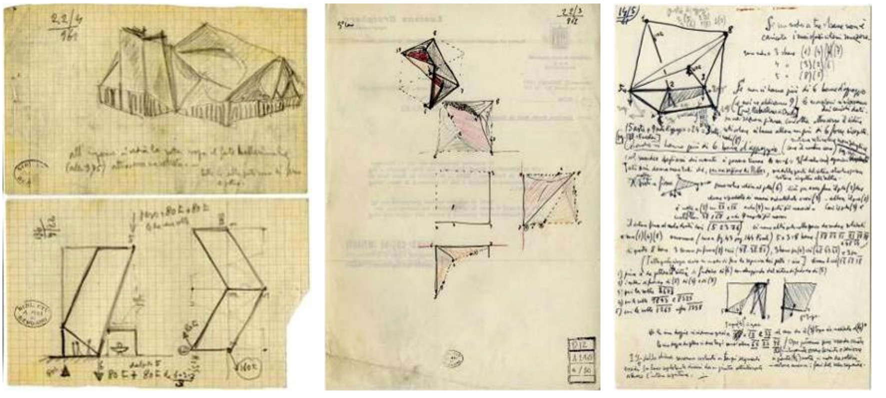

Fig. 5: steps of the shell design [9] – A-210, 1-11

The concept of Möbius Ring is easy to find even in the very first sketches: it was nothing more than a suggestion, but it clearly aroused Pizzigoni's curiosity. He understood that, by connecting different hypars, it was possible to design a complex shape which was, at the same time, quite easy-to-build and cheap: but he also found that, by twisting the sequences of the shells, linking the first and the last one in a Möbius Ring, it was possible to obtain a very uneven, complex shape (Fig. 6). As his main formal research was related to the internal effect of the shape, he found that this solution was very effective.

Fig. 6: sketches of the Möbius Ring [9] – A-210, 1-11 and 2-11.

The third concept, the God's Tent, was the metaphor leading all the following design steps. The internal shape had to result in a single, smooth surface, composed by different parts which had to seem like belonging to a sole drape. This metaphor was quite obsessive all during the design, as Pizzigoni himself drew a lot of sketches of stylized human figure, representing Biblical Subject, particularly the Madonna (Fig. 7).

Fig. 7: sketches of human figure, stylized to became a complex shape [9] – A-210, 2-11.

3.3. The final project and design methods

The church spans over 900 square meters, with a maximum height of 18 meters: it is divided in 4 identical free parts, which form a perfectly symmetric, centrical layout church. It is thereby quite unexpected that, despite the continuous references to hypars and the importance of the vaults, the entire design process is taken on only working on frame configurations of bars, without any thought about hypars indeed (Fig. 8).

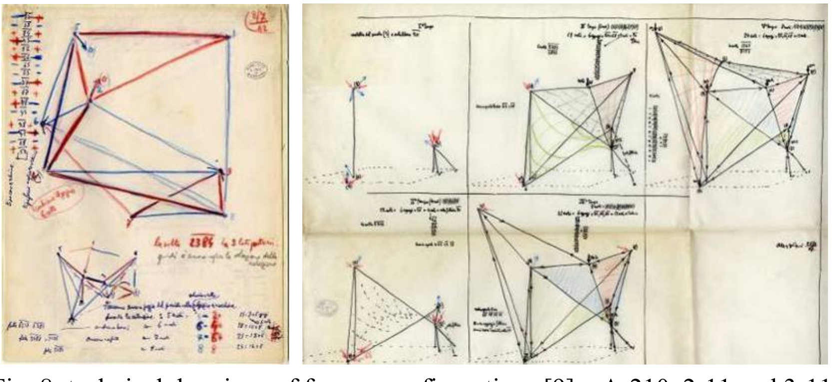

Fig. 8: technical drawings of frames configurations [9] – A-210, 2-11 and 3-11.

The main notions of Pizzigoni about hypars are numbered, and concatenated, by himself in the descriptive reporting ([9] – A-210, 5-11, and [5]):

- the building of hypars is very simple, as you can use right stripes-composed formwork.
- reinforcing rods are set in diagonals direction: they will be parallel in the top projection, and will be parabolic.
- the reinforcements transfer only axial stress to the bars.
- every hypar shell has two edges in tension, and two in compression.
- every shell can be considered as a fixed-joint frame of four points and six bars, among

which four are the edges of the hypar and two link the points as chains. So the shell has not to be considered while calculating the whole structure.

- apart from the calculation of the frame, further attention are to be given to shear stresses in the supports and the thickness of the shell.

The main point is the possibility to calculate the whole structured as a fixed-joint frame: all during the design, Pizzigoni tried to find a possible frame that is statically-determinate and aesthetically pleasant, not considering the presence of hypars but by adding axial stresses to the bars, calculating the shell apart from the frame. This is why the great majority of the sketches are related to frame configurations, with the number of bars and of point changing depending on the structural calculations. Everything was done by using drawings and numeric tables describing the frame, in which the shells are then added as a sketch.

Physical models were realized, in different scales and materials: but they were not used as an aid to design. The aim of the smallest ones was essentially to communicate the spatial result of the project, like the continuity of the covering or the structural "lightness" (Fig. 9). Only one model was build at a (possible) scale of 1:5, to show building methods to the developer: despite the trust of the architect about building ease of hypar shells, the call for tenders was deserted many times, probably for the oddity of the buildings [5]. Finally, the property developer Gianni Borella accepted to build the structure for a total cost of 40 millions lire. When completed, the church knocked back a modest cost of 75 millions.

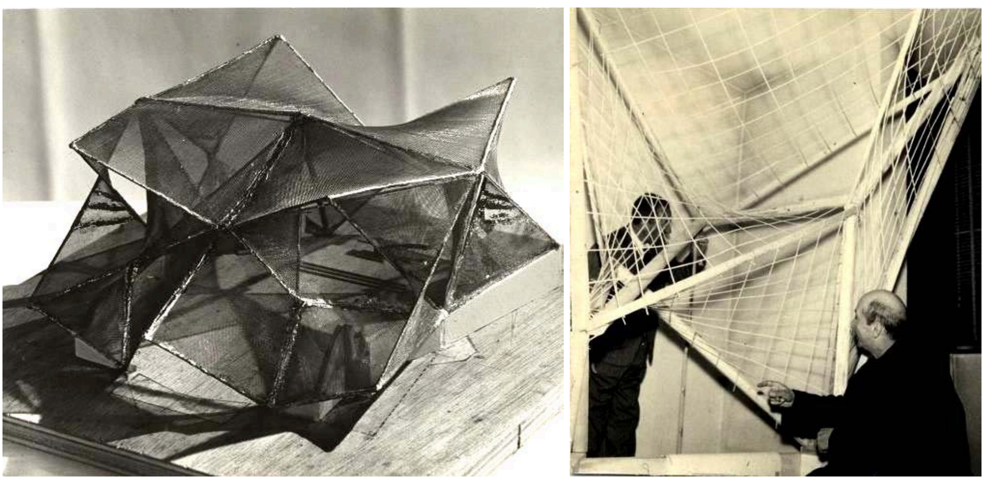

Fig. 9: physical models of the Church and of a quarter of the shells [9] – A-210, 8-11

4. Structure + form

4.1. Description of the structure

Apart from the hypar shell of the entry and of the apse, which is free, not connected to the whole structure, the Church is composed by four identical and symmetrical parts, connected and divided by two joints. By isolating a quarter, with the aid of a virtual model it is possible to understand the composition of the apparently inextricable vault (Fig. 10).

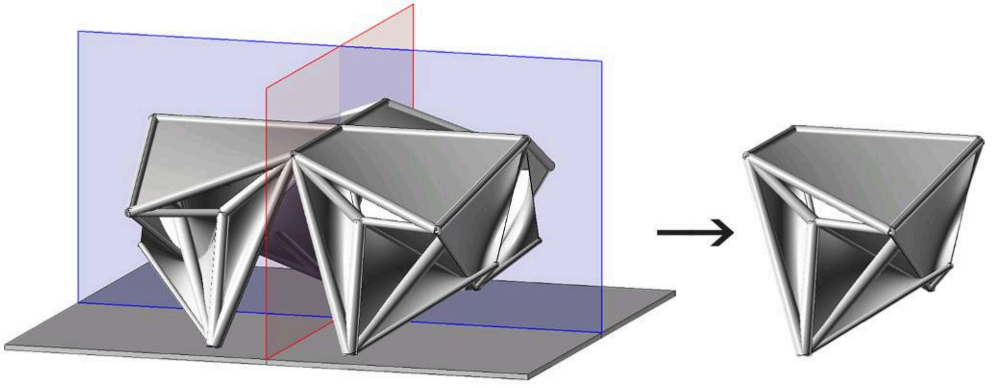

Fig. 10: Virtual model: division of the Church in four symmetrical parts.

Four surfaces, joined together, shape a starting ring (Fig. 11, a) that is then topologically transformed in a Möbius Ring (Fig. 11, b). Moving four nodes, a whole deformation of the surfaces is added obtaining four hypars (Fig. 11, c). A fifth one (Fig. 11, d), partially capping the hole between the first four shells, is then added: the remaining hole is closed with a moderate and unpretentious stained-glass window, which softly lights inner space with reflected light.

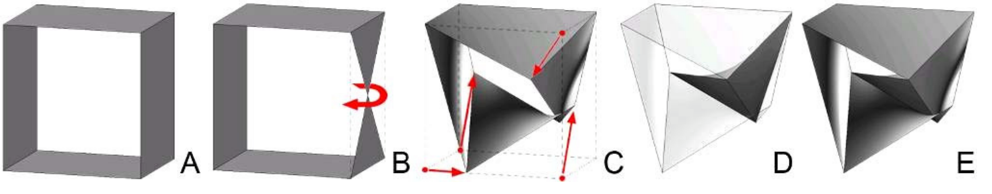

Fig. 11: evolution phases of vaults disposition: a) the ring, b) the Möbius ring, c) geometrical deformation, d) fifth hypar, e) final configuration.

Considering all hypars edges, it is possible to identify 14 bars creating the main frame of the structure (Fig. 12, a). Pizzigoni considers indeed 8 edge bars plus 6 connection bars. This spatial configuration is completed with four more free bars (meaning bars that are not shells edges), drawn in cyan (Fig. 12, b), and three foundations bars (gathered in the building in a single crossbeam of generous dimensions) drawn in green (Fig. 12, c). Note that two of the three foundation points are nearly coinciding. Total number of bar reaches 21, and nodes are now 9. The system become statically-determinate, as described Pizzigoni who applies the Maxwell Rules, by adding six more external constrains and can be easily calculated. In fact, 21 bars + 6 constraints = 9 nodes x 3 = 27.

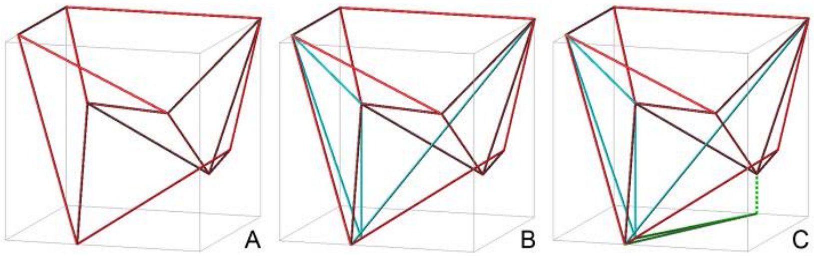

Fig. 12: evolution phases of space frame: a) 8 main bars + 6, all edges of vaults (red), b) 4 free bars (cyan), c) 3 foundation bars (green).

4.2. Structural behaviour

Pizzigoni described in the technical report of the church, conserved in two different versions in his archive [9] – A-210, 3-11, and then partially published in an advertising brochure [5], the procedure that he followed in order to calculate the spatial frame and the whole structure. Unfortunately, the synthetic written parts, compared with the few diagrams found in his archive, present some inconsistencies, here highlighted.

A first doubt is related to the static determinacy of the spatial frame. Pizzigoni says, referring to Maxwell rule, that a structure composed by 9 nodes and 21 bars, adding the six external constraints is statically-determinate. But he also says that he can substitute every shell with two chains in the direction of the diagonals of the edges: which is quite incorrect, all the more because he does not include these chains in the frame calculation.

A second unclear point is the definition of structure loads. It was analyzed without any considerations about shells, which are defined as rigid bodies, only applying nodal loadings derivate from shells weight (fixed at 400 Kgf/m^2 plus 200 Kgf/m^2 of snow, for a constant thickness of 5 cm). Pizzigoni considers two nodes vertex of hypars totally unloaded without any explication about his method of subdivision of vaults weights. In this way he simplifies further the spatial frame eliminating six bars that he considers totally unstressed. His results has been redrawn in Figure 13, a. In order to understand the real structural behaviour of the structure and therefore reconstruct his calculation process, we followed two parallel ways: a first FEM analysis of the spatial frame, considering his unclear loading condition, has been made. As you can see in Figure 13, b, the structural behaviour of single bars is radically different; a second FEM analysis has been processed reconstructing entirely the structure loading condition, starting with a geometrical method for an approximate subdivision of vaults weight for each node. The results are reported in Figure 13, c, demonstrating another time different behaviour of bars in the whole frame. The total applied load (5000 Kgf) is now the only correspondence to Pizzigoni calculations.

A third point of inconsistency between his report and drawings [9] is again related to bars behaviour. Referring to the theory, Pizzigoni states that of four sides of a doubly curved hyperbolic paraboloid, two are always compressed while two are tightened. As a consequence, in this structure there are 14 bars that are vaults sides, 7 compressed and 7 tightened. This sentence does not correspond to the scheme he draws [9] – A-210, 3-11, that represents 8 tightened bars and only 6 compressed.

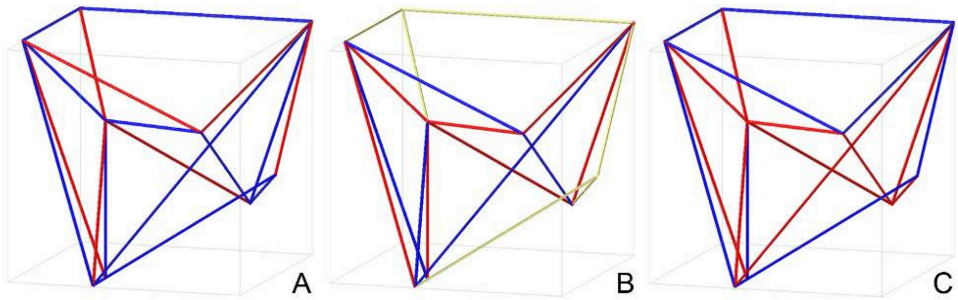

Fig. 13: structural behaviour of the frame (compressed bars are drawn in red and tightened in blue): a) as drawn by Pizzigoni in [9] – A-210, 3-11, b) results of a FEM analysis starting from loading conditions as defined by Pizzigoni in [9] – A-210, 3-11, c) results of a FEM analysis from a recalculated loading condition.

Indeed, any tentative reconstruction of the process followed by Pizzigoni in order to understand his structure behaviour is intended to fail. Due to the lack, at the time, of analytical tool and software, engineers were not able to manage these complex spatial configurations with a high degree of certainty: moreover, the absence of comprehensive normative rules gave to designers, with a certain amount of irresponsibility, a general sense of freedom in defining their structures on the base of their own instinct. That's why built elements are always characterized by generous section, with a precautionary approach.

5. Building details

5.1. Building materials, elements and processes

In spite of the spatial complexity of the structure, it was entirely built in RBK 500 resistant exposed concrete, by starting from foundation beams, having an exceptional section of 4x3,3x16,5m, and then adding vault, realized using a regular distribution of 12 mm thick reinforcement rods and with a minimum thickness of claddings of 5 cm (Fig. 14 a, b).

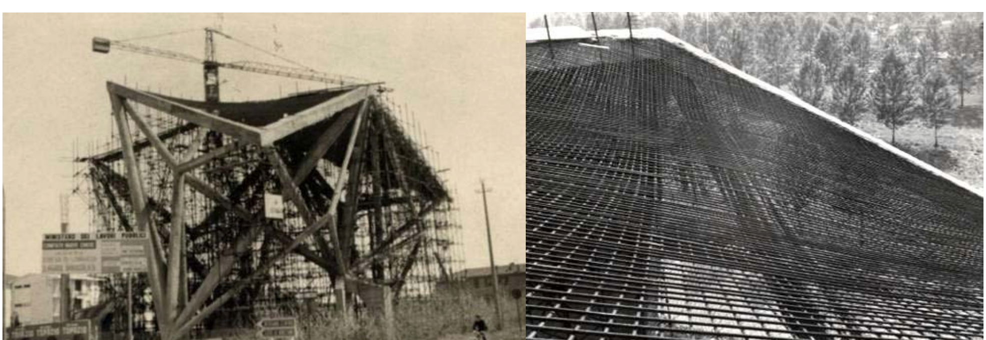

Fig. 14a ,b: pictures of the building site [9] – A-210, 11-11 and 10-11.

Due to difficulties in constructing and handling concrete formwork, we could suppose that all circular sectioned bars were realized by a pre-cast process, and then joined at the nodes, and only rectangular sectioned ones were cast in situ. The bars have variable section, with diameters going from 30 to 80 cm, but because of above-quoted questions, it is quite uncertain to determinate their behaviour on the base of their section.

5.2. Present status

Due to limited budget, only some parts of outer surface were daubed in grey, which uniform surfaces' colours with those parts whose concrete is exposed. Daubed parts are the most visible and exposed to rainfall: this is why after about fifty years the whole building presents an uniform level of degradation. Main problems are related to concrete cover in many parts of the structure and on the effects of rainfall actions, which corrupted some parts and stained most surfaces. In some case, it was quite impossible to correctly cast the concrete over the shells, as it's clear by looking at the rough surface finishing (Fig, 14 b).

Fig. 15: present status of the building: a) internal point of extreme curvature of a vault, b, c) bar cover degradation.

6. Conclusions

The church of Longuelo is of highest interest for the study of complex spatial structures, that was a diffuse interest among architects and engineers of that period. Pizzigoni was a local pioneer that took advantage of two main experimentations with spatial structures, which from the Fifties were explored: ambitious space frames, like domes by Buckminster Fuller or the Atomium, and concrete complex surfaces, mainly used by designers such as Candela and Torroja. Both avant-gardism techniques were used by Pizzigoni for conceiving this project, which became an extremely innovative structure. The synergy between structure and form is obtained by an extreme conceptual simplification of a very complicated shape that makes it possible for the architect to control it. Moreover, the approach to the structure of Pizzigoni is quite stunning: it appears that his consciousness of frame behaviour is more intuitive than rational, as we see that even in the final reportings, and also in the aftermath, the descriptions of the church and its structures show many mistakes and misunderstanding. The use of the simple concepts of spatial frame and hypars properties make it possible to reach an extreme formal complexity.

However, both the community and the priesthood were quite critic about the church, mainly because of its odd shape. Looking at the church it is evident indeed that it also lacks a connection with the neighbourhood: standing in a corner of its field, facing a minor street without any churchyard, being almost invisible because of the trees, looking only after the inside, it finally fails to be a real landmark, as usually churches are expected to be. Moreover, the harmony between the centrical layout and some of the rules suggested by the 1962 Second Vatican Council, claimed to be a value of the church, appears to be quite fortuitous, more than intended. But, despite of critical architectural considerations about it, the church of Longuelo is surely an utterly interesting case of holistic approach to spatial structures, whose experimental character should be further investigated.

Acknowledgement

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