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design and construction of an experimental structure

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The church of Longuelo by Pino Pizzigoni: design and construction of an experimental structure

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Introduction

During the twentieth century, several Italian architects devoted their efforts in finding a synergy between structural and formal character which was economically reasonable while rich in new architectural opportunities. Among the most notable architects were personalities like Pier Luigi Nervi, Luigi Moretti and Sergio Musmeci, but also a lot of almost unheard-of architects, whose works are of great interest.[1] Most of the experimental character of their buildings was related to the use of concrete shells and structures, which became quite common in Italy after the 1960s. They were initially applied mainly in industrial and sport buildings, where large spans were required, usually using ribbed or groin vaults. However, soon the fascinating formal properties used abroad by such personalities as Felix Candela inspired Italian architects to experiment with concrete shells in religious buildings as well, where vault shape often plays the most important role.

This structural culture became particularly popular in the area of Bergamo, in the north of Italy: we can ascribe this singular concentration to a series of circumstances such as the presence of Italcementi, the most important concrete manufacturer in Italy, and of ISMES, a research institute related to structural knowledge, which some years later would take part in the International Association for Shell and Spatial Structures (IASS), founded in 1959 by Eduardo Torroja. However, the intellectual and artistic climate was also favourable to the diffusion of new formal character, mostly due to Nino Zucchelli, director of the "Mostra Internazionale del Film d'Autore di Bergamo" (International Movie Festival of Bergamo) and several other events where artists discussed new possibilities of formal expression, in which architecture was absolutely included. In this cultural climate, several engineers like Enzo Lauletta co-operated with architects like Vito Sonzogni and Giovanni Muzio to experiment with the expressive potential. [2] Those designers, who sought a new link between art and technique, began to be called "arch-engineers". In this article, one of these designers, namely Pino Pizzigoni, is presented along with his first experimental buildings leading to his last masterpiece, the church of Longuelo, to which the main part of the article is devoted.[3] The first section of the paper describes the multi-faceted personality of Pizzigoni with special attention to the last years of his life, looking at his experience with concrete shells. The second section presents an overview of the church project to understand its genesis and evolution. The third section elaborates on the structural behaviour of the church, as the description by the architect is often confusing. In the fourth section the construction history of the church is presented, while in the fifth we look at the present status of the building and its ageing. Finally, before the concluding remarks, the sixth section considers the influence that the church had at its time on the intellectual and architectural climate of Bergamo.

The main information related to this building has been found directly from Pizzigoni's archive, located in the public library of Bergamo "Angelo Mai"[4] where his own sketches and written records are preserved, in the private archive of Longuelo parish[5] and from interviews with architects Attilio Pizzigoni and Giovanni De Vecchi. The church appears in a series of publications, both monographs and reviewed articles: however all the publications simply quote the descriptive reportings by Pizzigoni, or theorize about the poetic conception of the architect.[6] None inquire into the specific design conception, nor the construction history, in which the true value of the project resides.

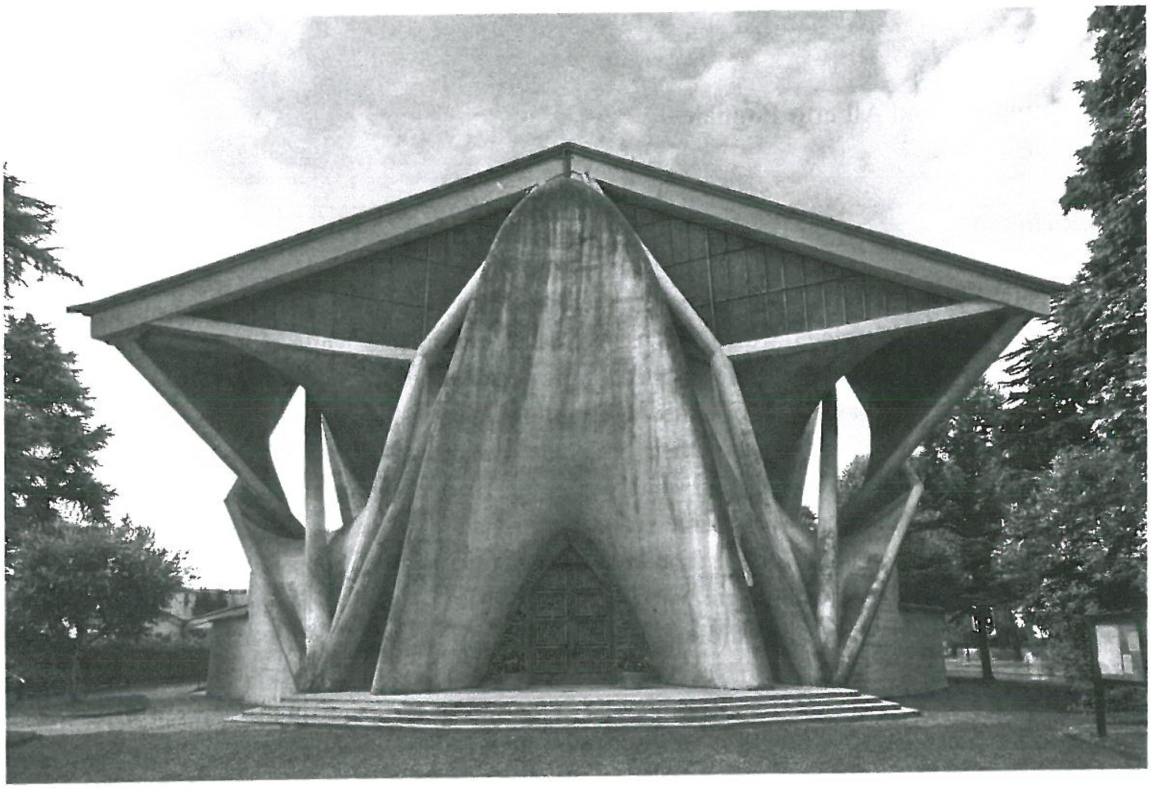


Fig. 1. Chiesa Nuova, Longuelo, Bergamo (1961-5): Exterior.

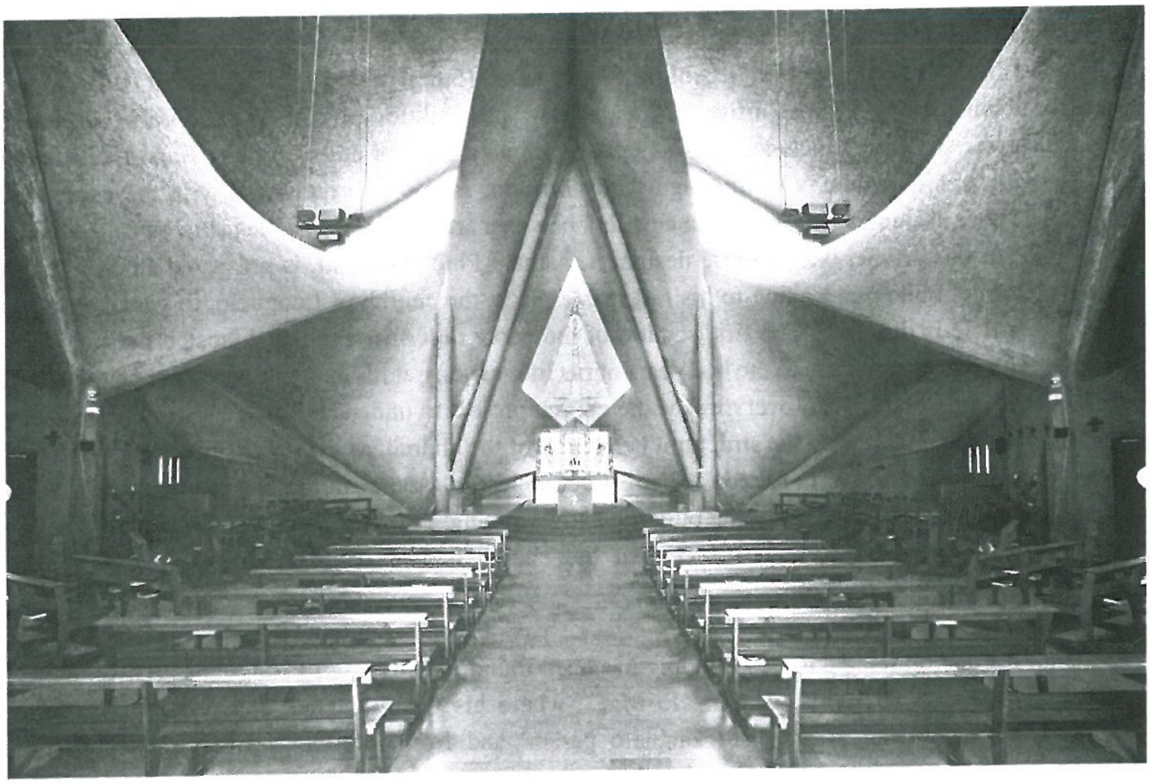


Fig. 2. Interior of the church, looking towards the altar.

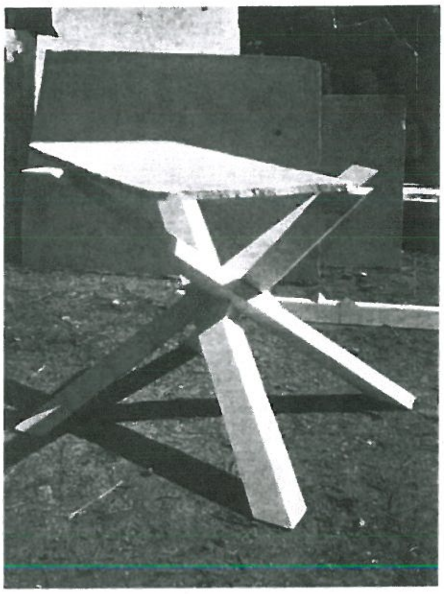
Pino Pizzigoni architect and engineer

Pizzigoni was born in 1901 in Bergamo, Italy, where he lived and worked and where he died in 1967. He studied architecture at Politecnico di Milano from 1918 with some of the most notable Italian architects of the twentieth century, like Terragni, Bottoni, Figini and Pollini. He graduated in 1924 with Gaetano Moretti as tutor and in 1927 he designed and had his first major project built, his father's house. The building immediately gained media attention, spreading architectural discussions about formal languages and monumentality. Just then the main cultural debate was about the possibility for Italian rationalism becoming the distinguishing style of fascism, but Pizzigoni never involved himself, nor became member of any political party. Quite neglected by architectural historians, he is usually described as a post-rationalist architect because of the duality of his works which were for the most part quite traditional, even if often high-grade buildings.

After the Second World War, Pizzigoni devoted his interests to new structural typologies such as shells and spatial structures, following the rising "philosophy of structures" concept. In spite of lack of publications in Italian architectural journals, outstanding South American projects, as well as European examples like Le Corbusier's Philips Pavilion and most of the pioneer work by Franz Dischinger in Germany and Eugène Freyssinet in France, were known by Pizzigoni who possessed several foreign books about them. Most of these buildings were essentially composed of a complex roof structure, largely independent of the construction plan: a contrast leading to unexpected although geometrically well defined spatial configurations. Pizzigoni was obviously fascinated by these new expressive possibilities, and due to his technical training he was able to decipher their complexity. He then began experimenting with simple full-scale models on a site on his own property in Zandobbio, near Bergamo, where he built several types of hypars (i.e. partial hyperbolic paraboloids), most of which have now collapsed.

However, Pizzigoni's very first structural experiments were not related to hypars, but to another very specific aspect of spatial structures, namely reciprocal frames. He most likely encountered these during his erratic investigation in the field of architecture, and began to investigate them by making experimental tables and chairs. He made a wooden chair in 1948 and an experimental marble table in the same year (Figs. 3, 4). However, the realization of these 1:1 scale prototypes was carried out very amateurishly, without any further specific theoretical deepening of understanding. Then his main interest moved to shell structures and the potential of hypars. For twenty years he honed his skills both with a theoretical approach and a true learning-by-doing process. One of his oldest books, dated 1952, is a French text entitled *Calcul des voiles minces en béton armé* that focused on the structural foundations of thin shells; it was probably the first text about shells studied by Pizzigoni. In addition, he surely knew the research by Franco Levi whose experimental studies published in 1957 are cited in his notes preserved in his archive.[7] In the same period, he built his first simple experimental shells in Zandobbio, where the double-curved hyperbolic paraboloid roof structure of a stable, dated 1956-1960 (Fig. 5) and a half-demolished umbrella structure, of unknown date (Fig. 6), can still be found. Some other experimental structures, now demolished, were built by Pizzigoni nearby, but a lack of written and photographic documentation does not allow us to reconstruct their history at present.

After these first trials, Pizzigoni began to apply hypars and shell structures in his real projects. His first building, in which the roof was made by a simple composition of hypars, was the Comana Marble Factory in Seriate, built in 1957. It was followed by two schools in Monterosso, dating back to 1959, but constructed in 1965. Here, a large span was realized by a typical sequence of hypars, but the inner space was organized without relation to the roof. Consequently the roof cannot be fully appreciated due to the presence of many dividing walls. In all of these projects it seems clear that the technology of hypars was applied by the architect only on the basis of potential cost reduction. The financial and building facets were studied for the most part without any experiment on the typology, on the use of space or on the spatial potential given by shell structures. From an architectural point of view, these projects are indeed quite embryonic. In his next buildings we can appreciate a further step in the exploitation of the formal properties of shells. A year later, in 1960, Pizzigoni designed pigsties for a cheese factory in Torrepallavicina (Fig. 7), completed in 1964.[8] Here, even if the functional needs of the pigsty were not related to the form of its cover, a greater attention to the spatial effects given by the hypars can surely be appreciated since the shells are very visible and their alternation is simple but effective.



Figs. 3-4. Experimental wooden chair and marble table by Giuseppe Pizzigoni.

Fig. 5. Stable with experimental shell, Zandobbio (1959-60).

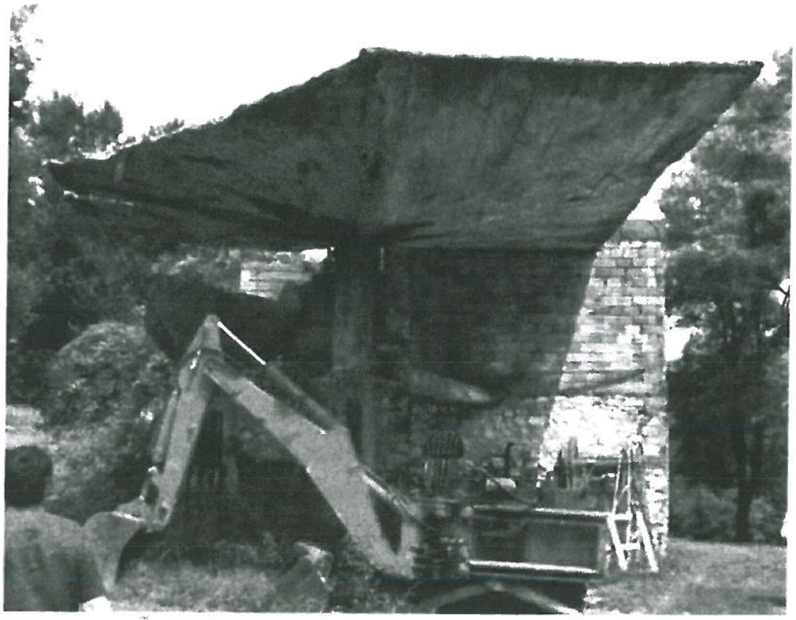


Fig. 6. Umbrella Structure, Zandobbio, Bergamo (1959-60)

Fig. 7. Pigsties for a cheese factory, Torre Pallavicina, Bergamo (1964).

After this first period, Pizzigoni consolidated his structural design skills within this area with new foreign publications, such as *Statique et dynamique des coques* dated 1960, *Introduction au calcul et a l'exécution des voiles minces en béton armé* dated 1961 and *Pièces longues en voiles minces* dated 1962, all belonging to his personal library. He would also have found a general overview about the growing production of outstanding shells in the French book *Les Structures en Voiles et Coques* dated 1962 as well as in various architectural journals. He was stimulated by these publications to research of greater complexity for the realization of spectacular spatial effects with these structural typologies, as seen in the Philips Pavilion by Le Corbusier of 1958 and in the St. Mary's Cathedral, Tokyo by Kenzo Tange of 1964, two master references for his next projects. The first example was not published in Italian journals until 1965, being only reported at the beginning by foreign publications, such as *Arts and architecture* and *L'architecture d'aujourd'hui* in 1958 and *Bauen und Wohnen* in 1959. However, it was a very well-known building and therefore surely known to Pizzigoni before his architectural conception of the Longuelo church, which followed the "tent" idea and was realized with a set of hypars. Indeed, the reference to the Tange's cathedral was directly cited by Pizzigoni in his notes.[9] These international examples were used by Pizzigoni both as formal models and as a way to legitimise his own work by presenting it as closely related to an international architectural trend.

This formative period of theoretical studies and simple experiment is essential to fully understand the evolution from the early buildings to the most complex and the subsequent structurally innovative ones, such as the Longuelo church (1961-65). In this project, Pizzigoni combined a spatial structure with a set of hypars with the function of cladding elements, with the purpose of creating a fascinating effect. Here the economic and constructional advantages of using hypars was almost completely put aside, or mainly used with the aim of convincing the promoter of the project. The formal potential of shell structures was therefore fully expressed.

Longuelo Church project

The church of Longuelo was the last main building to be designed by Pino Pizzigoni and can be considered his most innovative work, representing the sum of all experiments with shells made during the last twenty years of his working life (Fig. 8). He undertook the design of the church in 1960, although the first sketches in his archive are dated 1961. His final project was presented in May 1961,[10] then some minor changes were made to that version and, a few months later in September 1961, a slightly different project was submitted.[11] Construction started in 1962 and went on until 1965. The church was finally consecrated on June 29, 1966 by the archbishop Clemente Gaddi, who dedicated it to Maria Santissima Immacolata and placed the memorabilia of St. Alexander and Pius in the canteen. Several artists and companies were involved in the project, all being from Bergamo. The statue of the Holy Mary was designed by Dietelmo Pievani and carved by the carpenter Giovanni Mostosi from the Umberto Carrara company. The altar was made of red stone by the Marini company from Lovere, near Bergamo, and the tabernacle was made by the sculptor Claudio Nani.[12]

It was not the first time that Pino Pizzigoni had engaged with the subject of churches and chapels. In fact, he designed a dozen projects, often characterized by non-traditional approach to this theme, such as the project of a Crystal Church in 1952. Perhaps the most notable of these projects was developed for the International Competition for the Cemetery Church of Bergamo (Figs. 9, 10), which shows several similarities with the later Longuelo design. Both churches present a traditional plan composed of four symmetrical parts enriched by a complex covering. It is therefore not surprising that the project of the Longuelo church starts with a division of the plan into four identical parts, organized in a very unoriginal way, and goes on with the formal inquiry of the single roof. Pizzigoni himself, in a descriptive report,[13] claimed that the core of the project, the one which will decide its affiliation to the world of true art instead of one of mere buildings, was the possibility of recognizing in the final shape the action of will power, the role of light as sculptress, and the unitary formal conception of the vaults. The dream of Pizzigoni was to link the world of science and technical culture with that of the arts; the rational power of predictive calculation with the expressive strength of formal suggestions. Above all, the project was probably perceived by Pizzigoni as an unrepeatable opportunity to fully exploit his acquired experience with shells and spatial structures on a truly notable building: the majority of works he was requested to build were quite traditional, and he rarely succeeded in using hypars and complex coverings. The desire of the Parish to realize a true contemporary church, fitting to represent with its shape the new growing residential area of Longuelo, was a manifest chance to go beyond the design of small and middle sized private houses. That is most likely why Pizzigoni was so resolved to build something so unusual, maybe even odd.

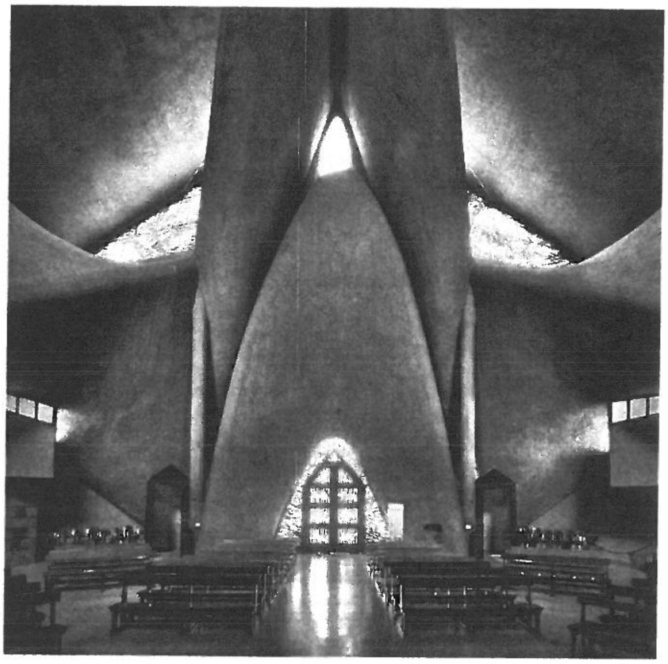
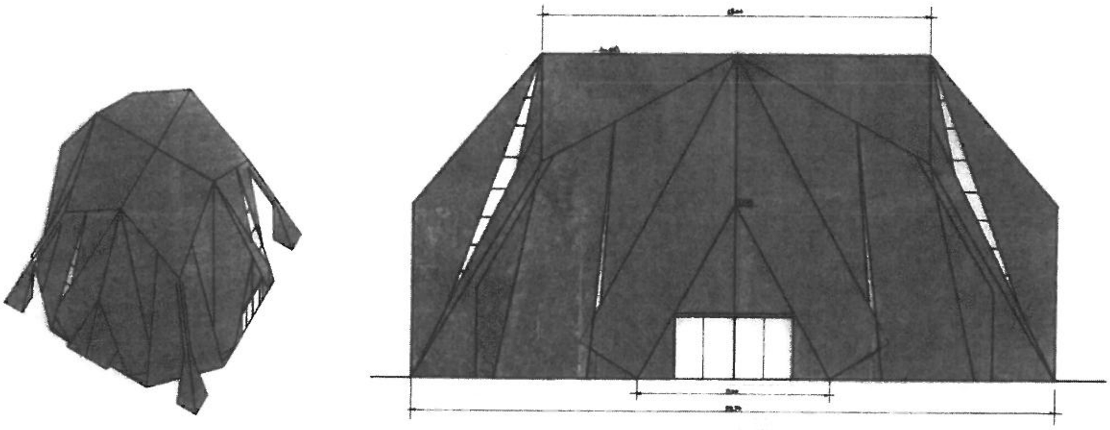


Fig. 8. Interior of the church at Longuelo, looking towards the door.



Figs. 9-10. Competition entry for the new cemetery church at Bergamo.

Since the first sketches of 1961, it is clear that throughout the design process there were three main propositions: 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 was Pizzigoni himself who claimed a number of foreign texts as references for his knowledge about hypars, such as those of S. Timoshenko, V.Z. Vlasov, F. Aimond, and V.V. Novozhilov. [14] From these texts and from further ideas of Issenmann Pilarski, he began to imagine a sequence of concrete shells whose shapes defined a single room. As previously stated, in practice Pizzigoni first decided to divide the church into four identical parts, and then began to study the structure of only a quarter by combining hypar shells (Fig. 11).

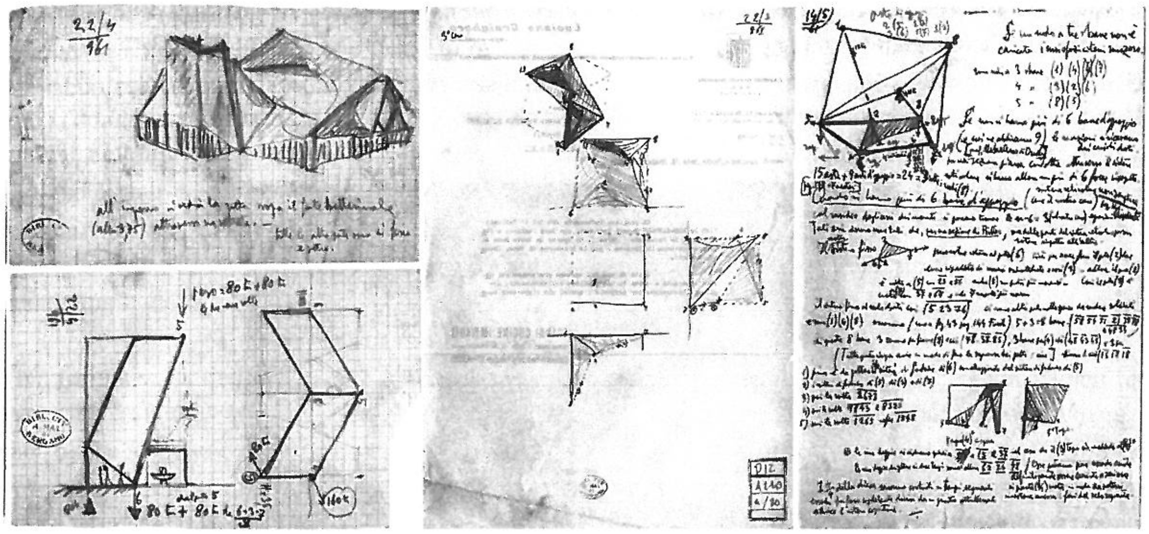


Fig. 11. Longuelo Church: the shell design.

The concept of the Möbius Ring is easy to find even in the very first sketches - it was nothing more than a suggestion, but it clearly stirred Pizzigoni's curiosity. He understood that by connecting different hypars, it was possible to design a complex shape which was quite easy to build and cheap at the same time. Moreover, he also found that by twisting the sequence of shells linking the first and the last one in a Möbius Ring, it was possible to obtain a very strongly-modelled and complex shape (Fig. 12). As his main formal research was related to the internal effect of the shape, he found that this solution was very effective.

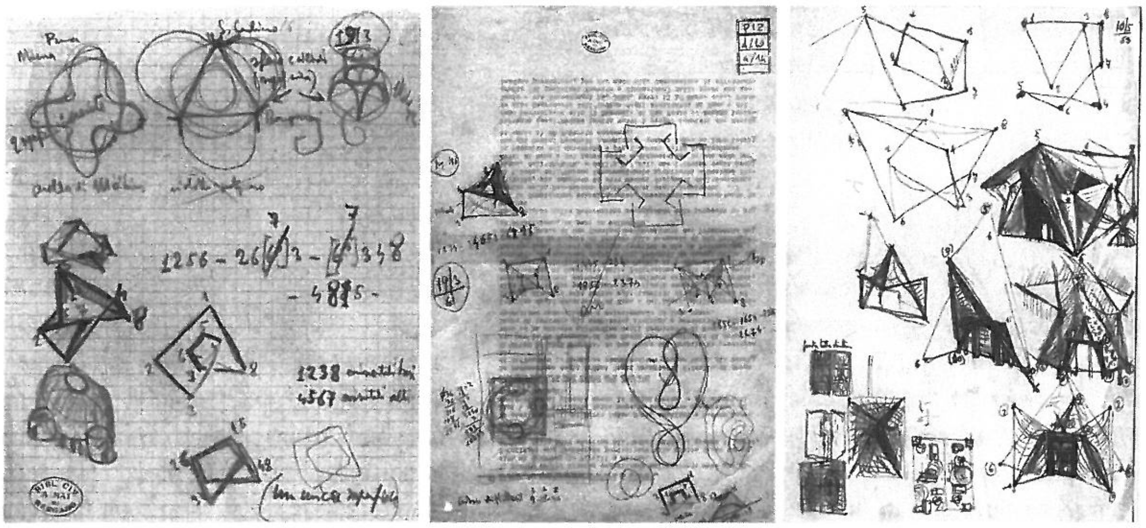


Fig. 12. Sketches of the Mobius ring.

The third concept, God's Tent, was the metaphor leading all the design steps which followed. The internal shape had to result in a single and smooth surface, composed of different parts which had to seem as belonging to a sole enclosure. This metaphor was quite dominant throughout the design process and Pizzigoni drew a lot of sketches of a stylized human figure, representing the Madonna (Fig. 13). But the drawings themselves are not so relevant, for it is the metaphor of the tent which has to be emphasized.

A tent is a very smooth shapeless covering, which encloses everything without exception, without any possible discrimination. It is indeed a very effective conceptualization of Christian charity, which is translated in the clear continuity of the concrete shells enlivened through a number of poles. The result is actually quite effective on the inside of the church while from the outside it does not seem to work at its best, as with most tent-inspired structures.

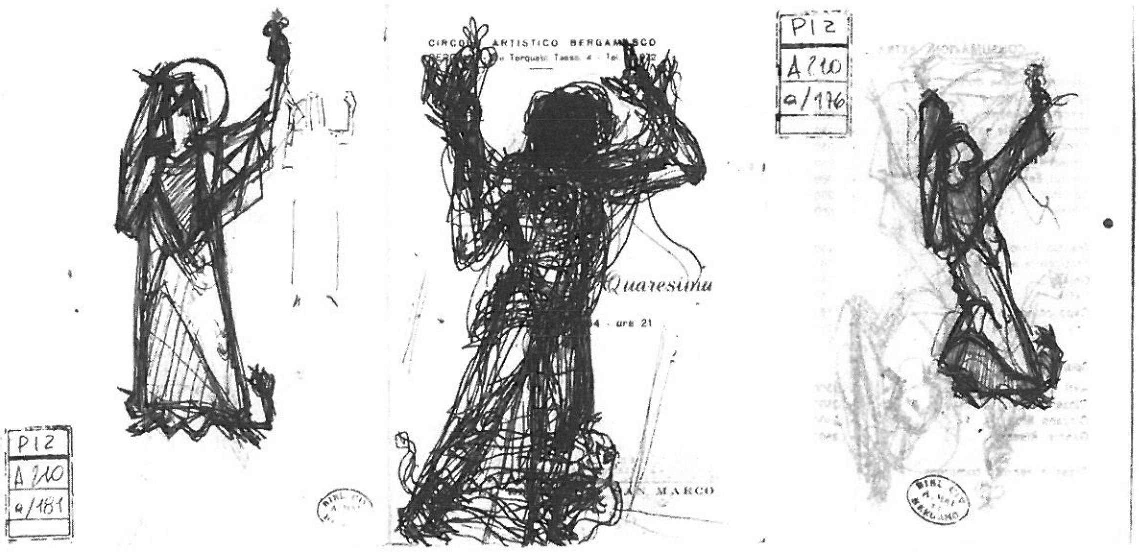


Fig. 13. Pizzigoni's sketches of the human figure, stylized as a complex shape.

The church spans over 900 sq m, with a maximum height of 18 m and is divided into four identical free parts which form a perfectly symmetrical, axial layout for the church (Fig. 14). It is therefore quite unexpected that despite the continuous references to hypars and the importance of the vaults, the entire design process was taken on with only work on frame configurations of members, without any thought about hypars (Fig. 15). In fact, Pizzigoni dedicated different pages of his notes to the topic of thin shells, describing all their various types. Moreover, he focused particular attention on the interesting possibility of composing different shells in order to obtain spectacular architectural effects.[15] Pizzigoni's main ideas about hypars are numbered and described by himself in the descriptive report,[16] also partly published in an advertising brochure.[17] The following list directly records what Pizzigoni wrote, including some of his inaccurate or completely incorrect notions. Some of these points are therefore commented on in order to highlight his errors and investigate why he stated them:

- the building of hypars is very simple, as you can use straight line-composed formwork;
- reinforcing rods are set diagonally and they will be parallel on plan, forming parabolic curves;
- the reinforcement only transfers axial stress to the frame members. [This statement is of course intended to simplify the real structural behaviour of frame members. However, it is incorrect. Also, the moments have to be transferred as well as the axial stresses as the shell surface is tied to its edge members, which have significant self-weight];
- each hypar shell has two edges in tension and two in compression;
- each shell can be considered as a fixed-joint frame of four points and six frame members, among which four are the edges of the hypar and two link the points as chains. So the shell does not have to be considered while calculating the whole structure. [This was a major point for Pizzigoni as it allowed him to calculate the structure as a pin-jointed frame, where each frame member removes only one degree of freedom from each node, which is very simple

even if quite inaccurate, as the edges and the surface are indeed highly interconnected];

- apart from the calculation of the frame, further attention is to be given to shear stresses in the supports and the thickness of the shell. [This "further attention" refers to the corrective factors that have to be applied to balance previous oversimplifications].

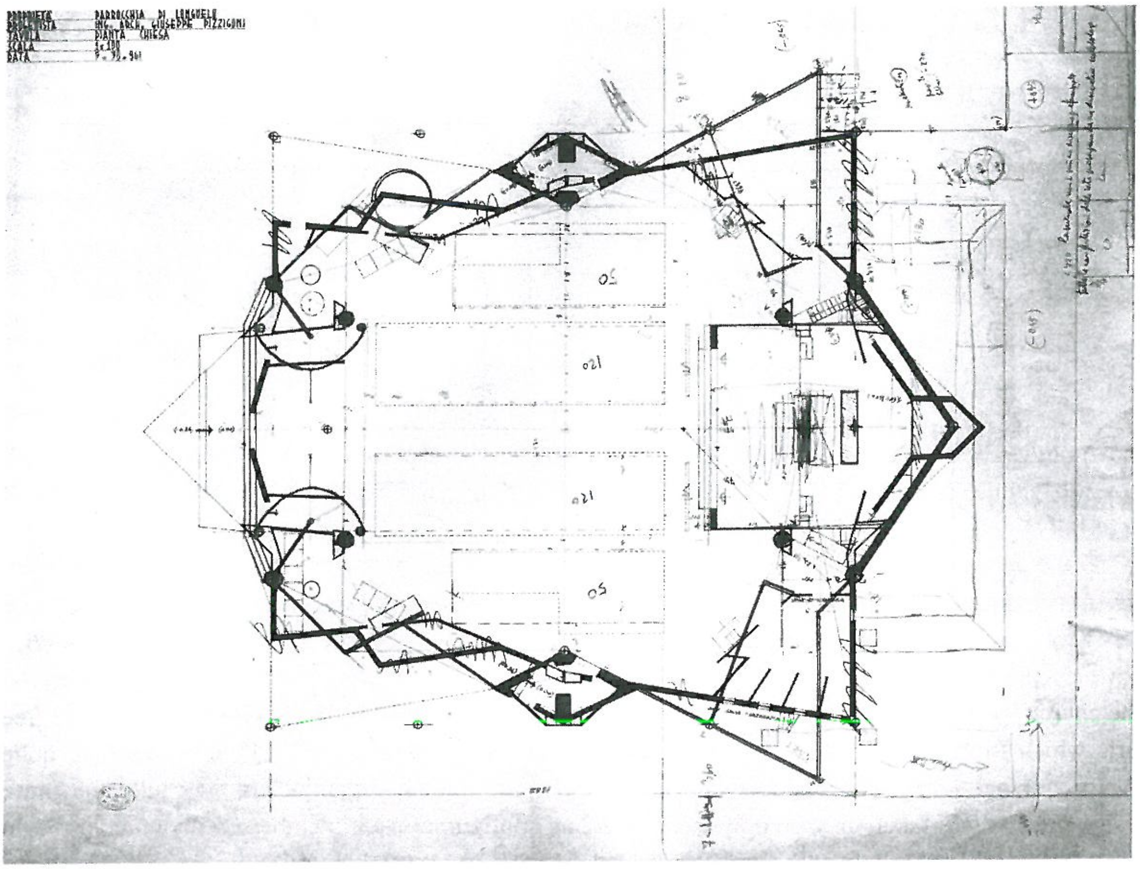


Fig. 14. Longuelo Church: plan, showing modifications made in the last months.

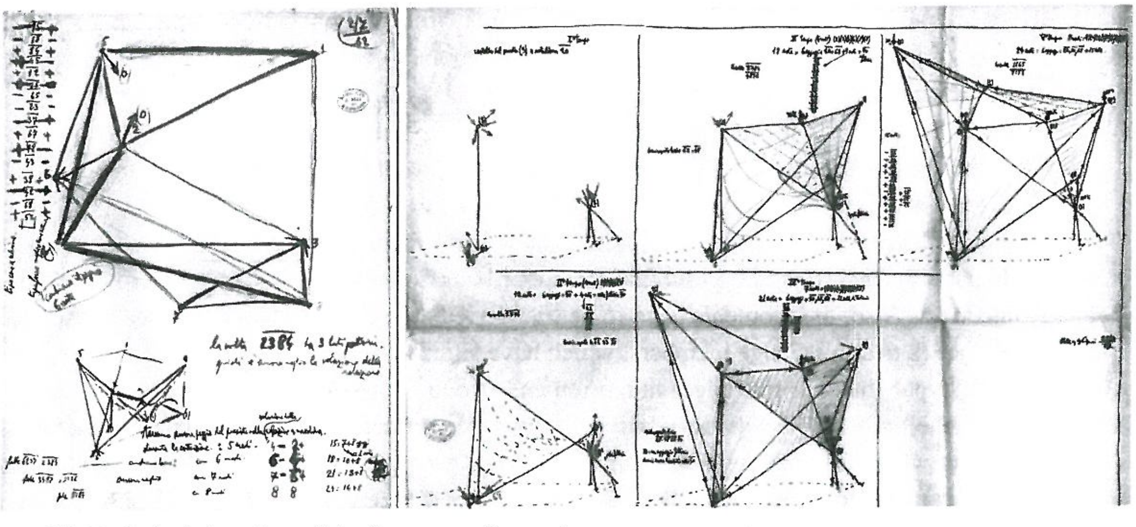


Fig. 15. Technical drawing of the frame configuration.

All these simplifications were simply needed. At that time there was no way to properly calculate such structures, but to oversimplify them, devolving the experience on the correction of these errors. Throughout the design process, Pizzigoni tried to find a possible frame that was both statically determinate and aesthetically pleasing, not by considering the presence of hypars, but by adding axial stress to the frame members and therefore calculating the shell separately from the frame. This is why most of the sketches are related to frame configurations with the number of frame members and point changing depending on the structural calculations. Everything was done by using drawings and numerical tables describing the frame in which the shells are then added as sketches. Physical models were built in different scales and materials, but they were not used as an aid to the design. The aim of the smallest models was essentially to communicate the spatial result of the project (Fig. 16), and the largest model, at a (probable) scale of 1:5, was used to show construction methods to the builder. Despite the architect's trust in the buildability of hypar shells, the call for tenders was unheeded many times, probably because of the oddity of the building.[18]

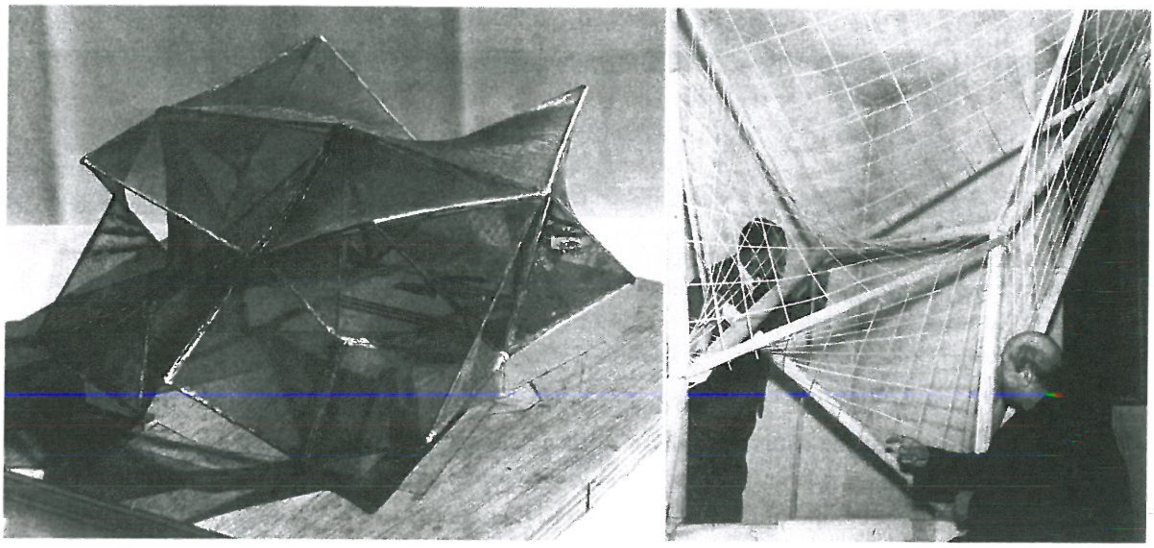


Fig. 16. Models of the church and of a quarter of the shells.

Structure and form

Apart from the hypar shells of the entry and of the apse, which are free and therefore not connected to the whole structure, the church is composed of four identical and symmetrical parts, connected and divided by two joints. With the aid of a virtual model, it is possible to understand the composition of the apparently inextricable vaults by isolating a quarter of the structure (Fig. 17). Each of these four parts is composed of five different shells. In order to better understand their spatial articulation, it is helpful to begin by only considering four of these surfaces which are joined together as if shaped in a ring (Fig. 18 A) that is then topologically transformed into a Möbius Ring (Fig. 18 B1, B2). Moving four nodes, a whole deformation of the surfaces is added obtaining four hypars (Fig. 18 C). A fifth hypar (Fig. 18 D), partly capping the gap between the first four shells, is then added. These four hypars do not define a closed shape: even when the four identical parts are joined together, some holes need to be capped. For this reason, the remaining hole is finally closed with a moderate and unpretentious stained-glass window, which softly lights inner space with reflected light.

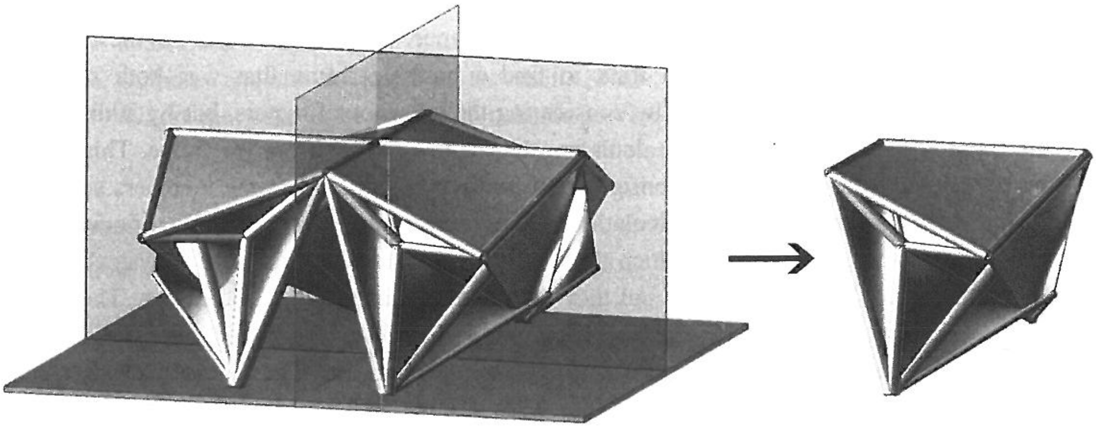


Fig. 17. Virtual model of the church, showing its division into four symmetrical parts.

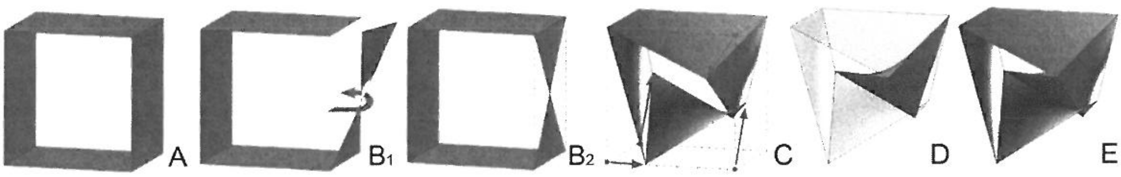


Fig. 18. Evolution of the vaults; (A) the ring; (B1,2) the mobius ring; (C) geometrical deformation; (D) fifth hypar; (E) final configuration.

These geometrical steps allowed us to reconstruct the overall generative process of the five vaults composing each quarter of the church. As these surfaces derive from a set of topological deformations, they are in fact very different from each other. This difference was theoretically not a problem as the hypars are easily built, but some of them (namely those that appear twisted in Fig. 18 B2) present such an extreme curvature that they were near impossible to concrete during construction (see section 5).

If we then move from the shells on to the frame members, we can easily decipher the intricate weave. Firstly, considering only the edges of the hypars, we can identify 14 members creating the main frame of the structure (highlighted in Fig. 19 A): eight edge members, the segments of the polygonal ring we saw above, plus four connection members, actually transverse to the development of the ring, plus two more connection members that define the shell of Fig. 18 D. The series of shells we saw in Fig. 18 is therefore defined by these 14 members. This spatial configuration is completed with four more free members, which are not shell edges (drawn in Fig. 19 B), and three foundation members gathered in the building in a single crossbeam of generous dimensions (highlighted in Fig. 19 C). Note that two of the three foundation points nearly coincide, a quite unexpected position which is probably due to the necessity of avoiding any intersection between the members and the shells. In this configuration the total number of members is 21, with nine nodes. To be able to calculate the frame, Pizzigoni needed it to be statically determinate. For this purpose, he applied the Maxwell Rule, which states that the number of members added to the number of external constraints has to be equal to the number of frame nodes multiplied by three. Therefore, Pizzigoni added six external constraints to the frame, obtaining a computable configuration. In fact, 21 members + 6 constraints = 9 nodes x 3 = 27. The Maxwell Rule is now satisfied and the frame can be solved considering only the nodal stresses (those given by the shells).

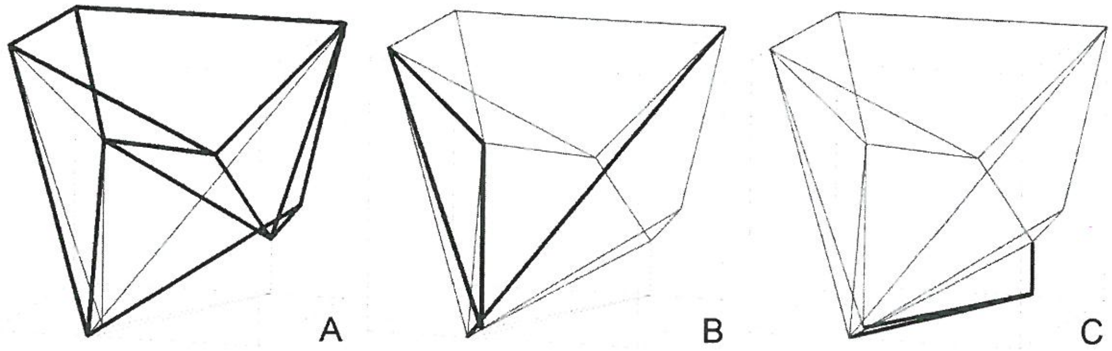


Fig. 19. Evolution of the space frame (the bars referred to are always highlighted with a thicker line): (A) 8 main bars plus 6 all shell edges; (B) 4 free bars; (C) 3 foundation bars.

As previously described, this complicated spatial configuration only defines a quarter of the whole church building, which is simply obtained by means of two axial symmetries. The sum of these four parts becomes a roof structure composed of 20 vaults and 84 members, connected with each other and thus giving a high sense of spatial complexity. However, this complex covering has no relationship with the internal organization of functions, which remains quite undifferentiated. But even if the covering has two axial symmetries, as shown in Fig. 20 A, the shapes of the single quarters successfully define a difference between a main direction and secondary one, as is clear from Fig. 17, where the space of the entrance is easily identifiable. Moreover, the presence of two extra shells, different from each other, structurally independent and used as walls, clearly indicates the main entrance and the apse (Figs. 23, 24). This creates an apparent negation of the centrical layout, transforming a generic bi-axial symmetry into a simple axial symmetry (Fig. 20 B), because the lateral symmetry is quite difficult to perceive when entering the church. This configuration makes the roof shape appear as a soft tent supported by several poles, overpowering its strong symmetry, and static character, and suggesting a one-way and dynamic perception (Fig. 20 C).

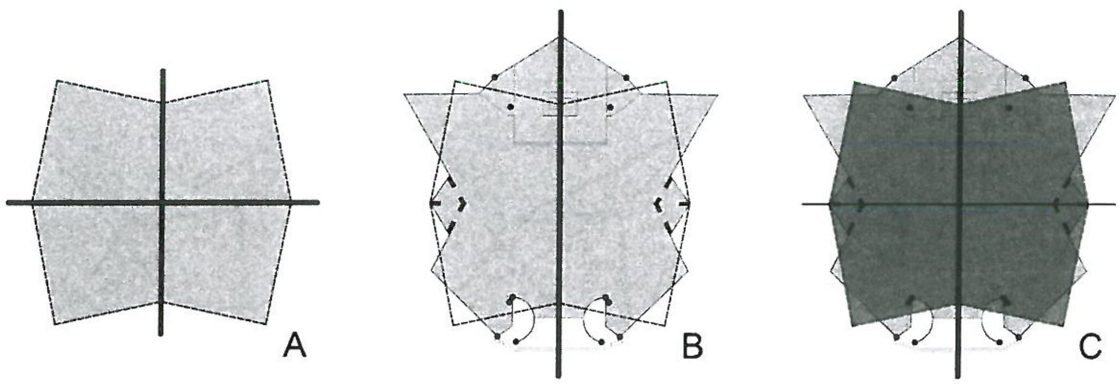


Fig. 20. The evolution of the plan.

The final configuration was therefore reached by trial and error, and is not so different from the first one. However, an attempt is made to solve the problem of intersection between shells and frame, which is very difficult to analyse even when using physical models, as the shape of the shells cannot be designed before the frame is defined. This means that there was a risk that the shells themselves intersected the frame members and this is most likely why Pizzigoni used a very long set of tables indicating different spatial coordinates. However, the problem does not appear to be completely solved and some beams are actually bent.

As we saw previously, the simplest way to understand the structural behaviour of the church is to divide it into four parts and to imagine each part as if composed of two major separate elements, an irregular frame and a set of shells suspended on it. The frame itself is a tangle of connecting members, some in tension and some in compression. Some members are considered to be non-loaded, because they are mostly there to make the frame statically determinate and thus calculable. The loads are essentially given by the weight of the shells and the snow load. Given these points, we can follow Pizzigoni in the development of the calculation procedure he applied, which can be found in the technical reports which have both written parts and explanatory drawings. However, in analyzing the reports, some inconsistencies become very evident and are highlighted here.

The first unclear point is about structural loads. The shells themselves were defined as rigid bodies, calculated as an all-in weight with a sum of 400 Kgf/m^2 (the weight of a theoretical 5 cm constant thickness shell) plus 200 Kgf/m^2 of snow, multiplied by the area of the shell. The loads were then divided among the related members. However Pizzigoni did not state how this division was made, nor why he did not apply any load to the two nodes (one of which belongs to the roof), which is quite unfathomable (Fig. 21 A). That is how he managed to further simplify the frame by considering six members unstressed (Fig. 21 B). This is inconsistent with what he drew in his own drawings, where all the members are either in compression or tension (Fig. 21 C). Probably, he calculated the frame with a simplified loading combination and then modified the results on the basis of his personal experience and feeling. The initial calculation was probably done on the basis of his idea about hypars, which described two of the four edges as in compression, while the other two are in tension. This sentence should explain why Pizzigoni postulated that, among the 14 edges of the shells (always considering only a quarter of the church), seven have to be in compression and seven in tension, but then his own schemes show a different and configuration not discussed, in which only six members are in compression and eight are in tension. As previously mentioned, this latest scheme probably took in all the intuitive corrections by the architect, who simply does not specify them in the reports. Moreover, Pizzigoni was able to approximate only the axial stress of the members, but as the shells are not separated from the frame, there will also be bending moments. In order to resist these, the proportions of the members were surely decided on the basis of his practical experience and thus generally overestimated. The members themselves are in fact quite large.

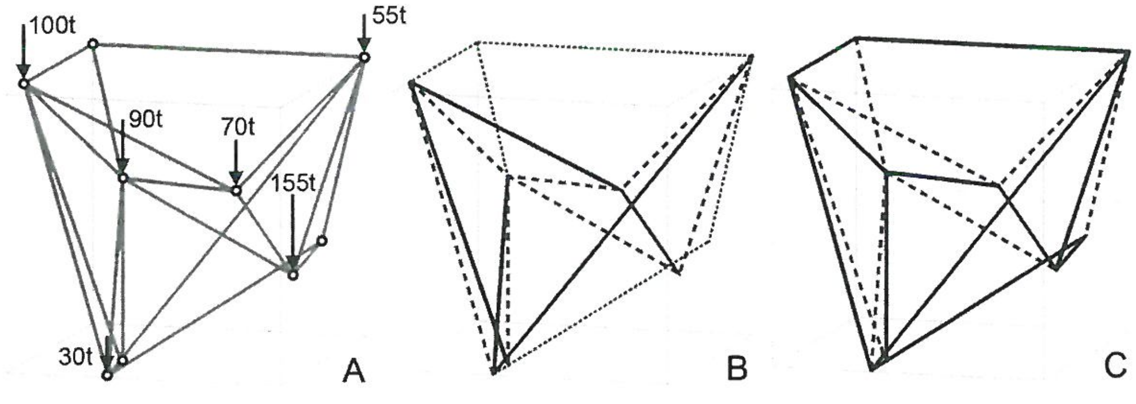


Fig. 21. Structural behaviour of the frame, as calculated by Pizzigoni (thick lines are compressed elements; dashed lines are tightened; dotted lines are unstressed): (A) load condition defined by Pizzigoni; (B)structural behaviour obtained with this condition; (C) structural behaviour modified on the basis of Pizzigoni's experience of spatial analysis.

It should be underlined that any effort spent reconstructing the process followed by Pizzigoni is destined to fail as all the corrections can only be hypothesized. Probably, the absence of comprehensive normative rules gave designers, with a certain amount of irresponsibility, a general sense of freedom in defining their structures only on the basis of their own instinct, and this is why the result is so extraordinary. A similar complex covering is surely an exceptional example of that "structural intuition" which nowadays seems so rare and which was so useful in managing situations characterized by high degrees of uncertainty.

Construction history

The final design of the church dates back to 15 September 1961, following various proposals. The alterations were always related to the frame and its spatial configuration with changes in the position of the nodes. In the descriptive reporting, materials and building schemes were enclosed with an accurate description of the groundwork and foundations. No drawings were found about the building of the structure, which has to be deduced from the very few existing photographs.

After a simple demarcation of the perimeter of the church, a symbolic foundation stone was laid on 24 June 1961 by Bishop Giuseppe Piazzi and the parish priest Vittorio Belotto (Fig. 22). The construction did not yet begin even if the design of the church was complete. Work on the site was suspended until 1963 due to difficulties in finding a builder and to the rising costs of the project. The church was initially designed for a very small community of about 3000 people, and then reconfigured to be suitable for about 5000 people. So the starting cost, estimated at 25 million Italian Liras to be paid from public funds, rapidly increased to 41 million, with the difference that this was to be paid by the parish itself. Compared with present currency (even if this calculation is indicative only) this means about 500,000 euros. This cost only included foundations and the main structure, and not the finishes and furnishings.[19]

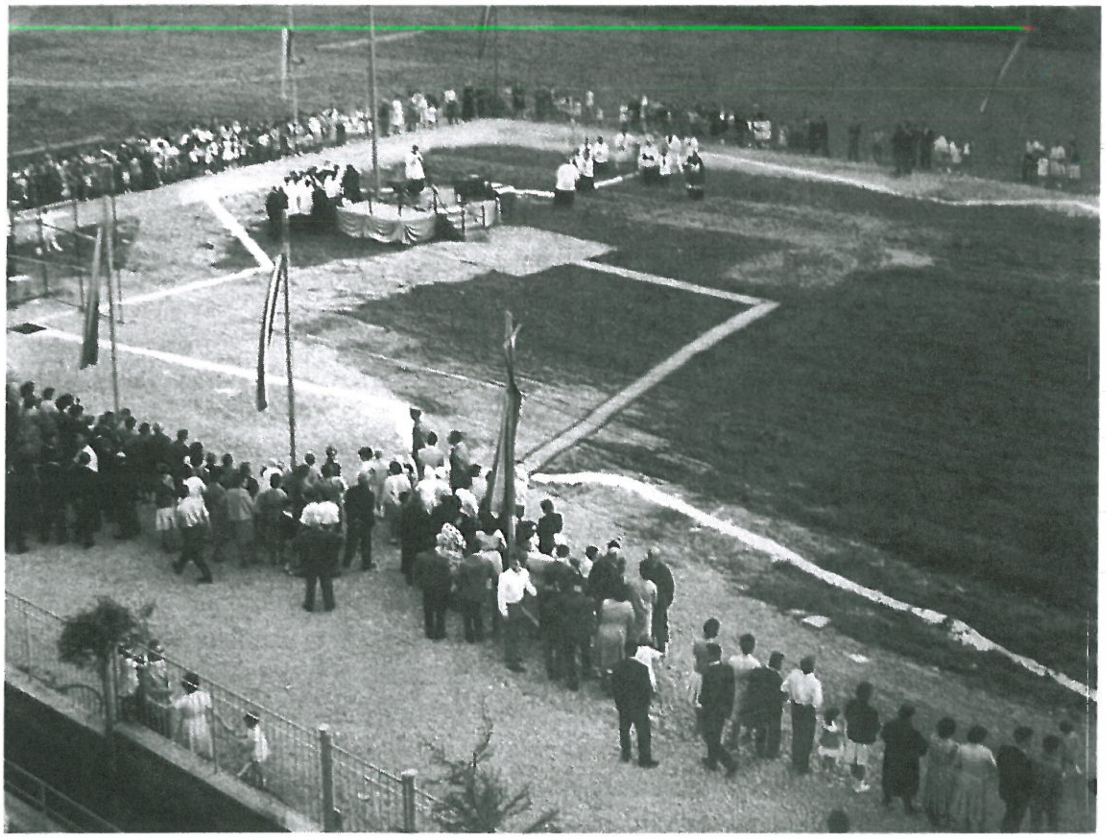


Fig. 22. Marking out of the church on the ground.

If we consider the lack of knowledge of shell structures, most builders were clearly reluctant to be involved, although the claims of Pizzigoni himself, who both in his descriptive reporting and in articles continuously stated the cost effectiveness of the shells, the initial outlay was quite relevant. For this reason, the first call for tenders failed and even in the second one in February 1962, when Pizzigoni revised his estimate up to 48 million, only one builder made an offer. The surveyor Gianni Borella, owner of the GENCOS building firm, made an offer to build the main structure for a total cost of 47 million, which was about 17.5 per cent higher than the initial scheduled cost with a modest 2 per cent discount bidding. The proposal was accepted, and building started with Pino Pizzigoni as project manager.[20]

The contractor started work in May 1963, almost two years after the completion of the design of the church, and the building site was then stopped for 182 days during the winter of 1963-4 until May 1964.[21] The overall cost rapidly increased, also due to some changes in the design such as a new portal designed as a separate shell standing forward of the main entrance (Figs. 23, 24), and some small shells to cover the sacristies at the east and west sides of the church. In addition, the roofing material changed from Embeco, a cement-based metallic-aggregate grout with an extended working time, to slate, aesthetically more pleasing, but also more expensive.[22] Apart from this it is difficult to understand the reasons for a similar increase of estimated cost, which finally reached 57 million in 1965, without ascribing to Pizzigoni an over-optimistic evaluation. The cost only related to the structure. Moreover, the floor, which covers over 900 sq m, consisted of a massive concrete cast instead of using excavated waste material, a much more conventional and cheap solution. Considering only the structure, this led to a total cost of about 60 million, which Pizzigoni justified by stating that the church should be able to work for a community of 6500 people, 1500 more than scheduled.

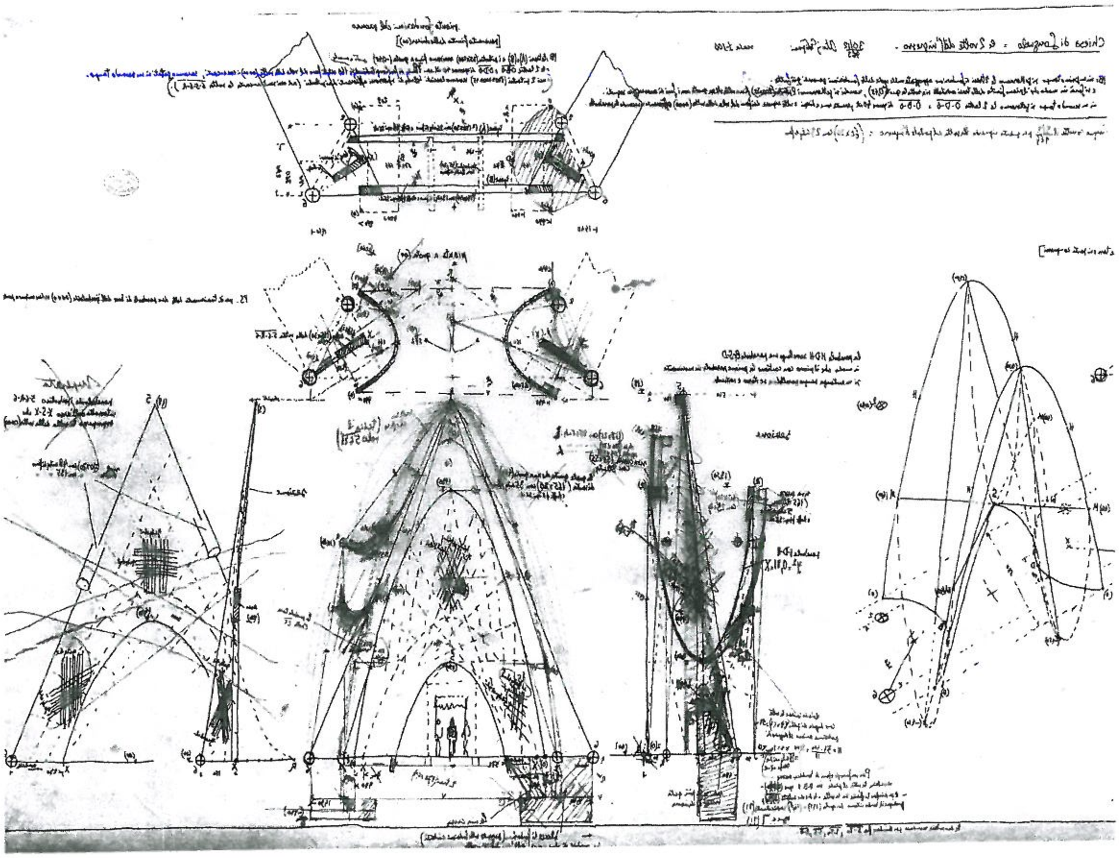


Fig. 23. Drawing of the entrance portal.

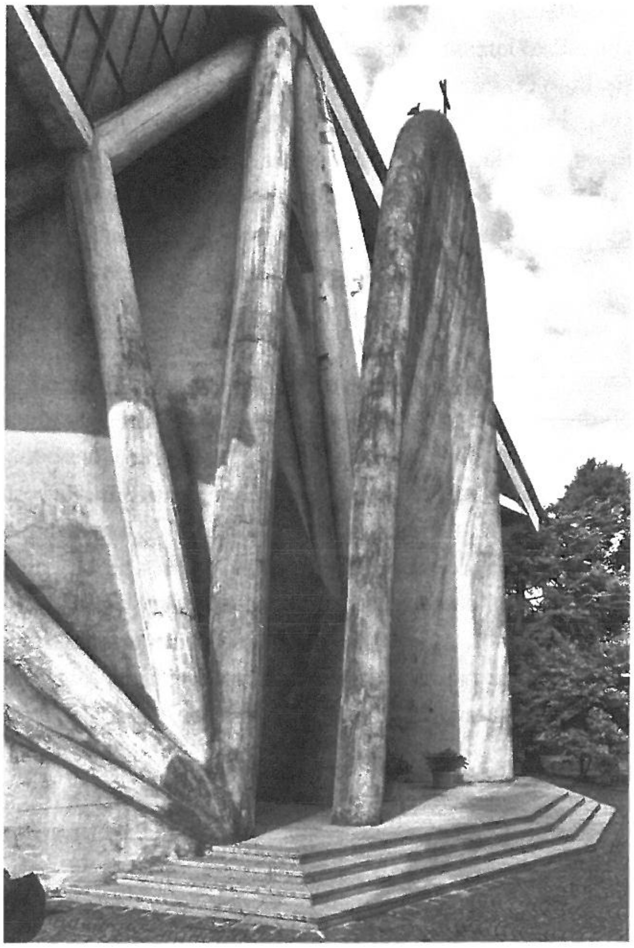


Fig. 24. Exterior of the portal shell.

The structure, comprising foundations, structural members and shells, was nearly completed in February 1965 at an additional cost of 4 million. Considering the starting budget of 40 million and the final cost (for the structure only) of 64 million, it is not surprising that the parish decided to dismiss Pino Pizzigoni from his role of project manager even if his project continued to be followed. The relationship between the architect and the parish had become quite strained, which was the cause of his dismissal. Tension was caused both by an architectural problem related to the shape of the church, which probably impressed the parish more after its completion than at the time of design, and also by financial problems as stated in a letter written to the architect on 7 October, 1964. In this letter the parish complained about unclear account management, requesting an audit.[23] Further confirmation of this strain can be found in several other letters, such as the one written to the parish priest Vittorio Belotti in June 1965, in which the architect replied to some critics of the unusual shape of the church and his own role and dismissal. And differences between the parish and the architect, who appears to have had the support of the Bishop, exploded again in 1966, when the *Eco di Bergamo* stated that "a major part of the roof collapsed due to project faults". Pizzigoni was identified as responsible by the parish on 16 August 1966, by means of a telegram sent by Vittorio Belotti.[24] However, it seems that only a small part of a gutter built after his dismissal collapsed during a storm and the architect answered immediately with a letter dated 18 August 1966, preserved in his archive in a draft form which does not hide the sour tone of the letter.[25] Probably to ease the situation, Pizzigoni gave as a gift the Madonna statue, which cost about a million. However, he treasured his role and the whole merit of the construction, as he stated in letters to *L'Industria Italiana del Cemento* on the occasion of the publication of the church in that journal.[26]

The building was finally completed and consecrated in June 1966. Including all the finishes (but not the furnishings, which had to be added later) it reached a cost of 75 million, double the original budget. Even though not being an overly high cost for such a church, it surely overtook the funds of Gianni Borelli, who went bankrupt after the completion of the building. Unfortunately, the archive of GECOM went missing after this, so at present we cannot follow the entire process through the drawings and documents. A parish house was built very close to the church, directly connected to it by a corridor, but effectively standing alone. The roof of this building is composed of a set of shells following a very simple sequence. Again, the use of hypars does not correspond to the enclosed space, demonstrating the indifference of Pizzigoni to integrating them in a traditional typology.

The entire structure, including foundations, frames and shells, was designed to be built in RBK 500 resistant exposed concrete, the most resistant type of concrete.[27] The foundations were laid as a system of three continuous ground beams for each quarter of the church. The exceptionally large dimensions of these beams, measuring 3.3 x 16.5 x 4 m, are explained by the type of soil, almost marshy (Fig. 25).They were cast in the summer of 1963, then the main frame was built. This was not exactly the same sequence as initially conceived by Pizzigoni, who reported in May 1961 that it was proposed to build first the foundations, then the five structural members per quarter which were directly connected to foundations, and finally to cast both the other members and shells at the same time. This original programme is quite difficult to understand as the frame can only work if completed. In fact, this perhaps-unaffordable solution was changed in the September 1961 report.[28]

Fig. 25. Casting of the foundation beams.

We know that in previous projects such as the school in Monterosso and the pigsties in Torrepallavicina, the frame members were cast in situ without any pre-casting work. Therefore we can assume that the same construction technique was applied when building the church. However, pictures showing the casting are unfortunately scanty. In support of this hypothesis, we can look at the results. Even if in the technical report Pizzigoni did not mention the shape of the structural members, he said that they had to be built with a rectangular section whose dimensions were determined by the peak load. Looking at the completed church, the members have variable sections with cross-sectional dimensions ranging from 30 to 80 cm. Some are rectangular, others cylindrical or spindled-shaped, and this was without any rational reason such as a possible relation between their form and their structural behaviour, or their function, i.e. to directly support glass frames. The most likely cause of this variety lies in casting problems as some members are quite strangely placed, and the casting technique in such situations was most difficult; there are some visible flaws such as some deflecting bars (Fig. 26). After the completion of the members, a regular distribution of 12 mm thick reinforcement rods (Fig. 27, 28) was placed in a diagonal direction, as stated by the shell theory. But from correspondence with the builder, it is clear that Pizzigoni was not so sure about the behaviour of the structure during construction. If the formwork of the edge members was removed before the hardening of the shell, the main problem in casting the shell was that the rods would be stressed by both compression and tension with the risk of them deforming. That is why just before the winter, when the rods were being distributed, Pizzigoni, in a letter dated 14 December 1963, strongly stated his perplexities to Mr. Borella about his independent decision to remove a vault scaffolding structure early.[29] He recommended that formwork was not removed until hardening of the concrete was complete. From the letter, it seems that Borella had been thinking of increasing the strength by welding the rods in some nodes, which confirms his lack of knowledge and experience. The building envelope was then built, with a thickness of 4.5 to 5 cm. When the shells were completed, after the main entrance shell was built, the finishing works were begun. Once that the now-replaced glass wall capping the space between the shells, the roof, and the floor (made by a massive concrete casting) was completed, the church was consecrated in June 1966, although it could not be used by the faithful until the completion of all other furnishing and finishing (Fig. 29).

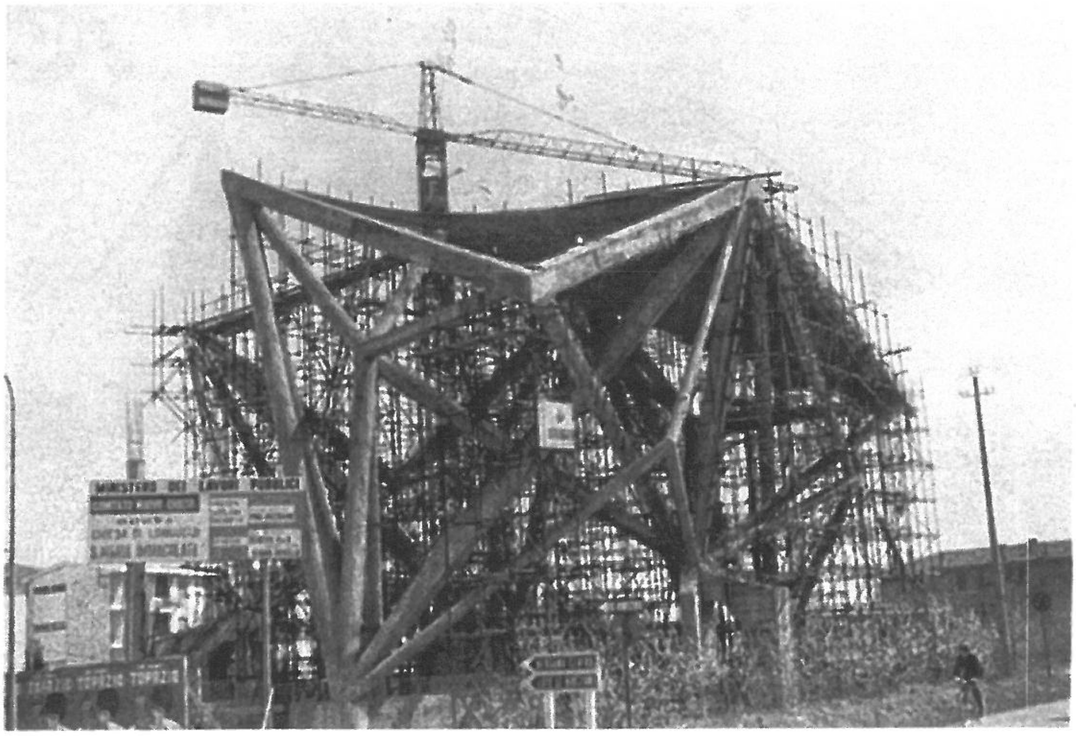
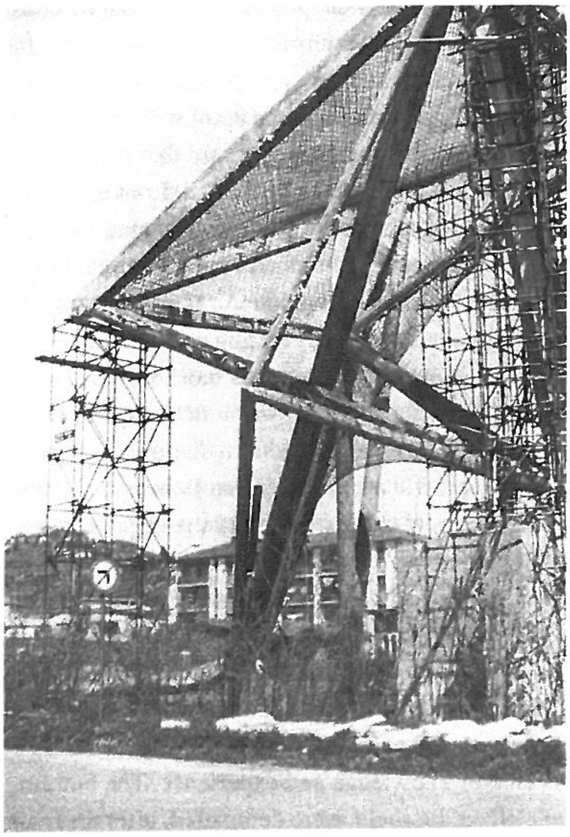
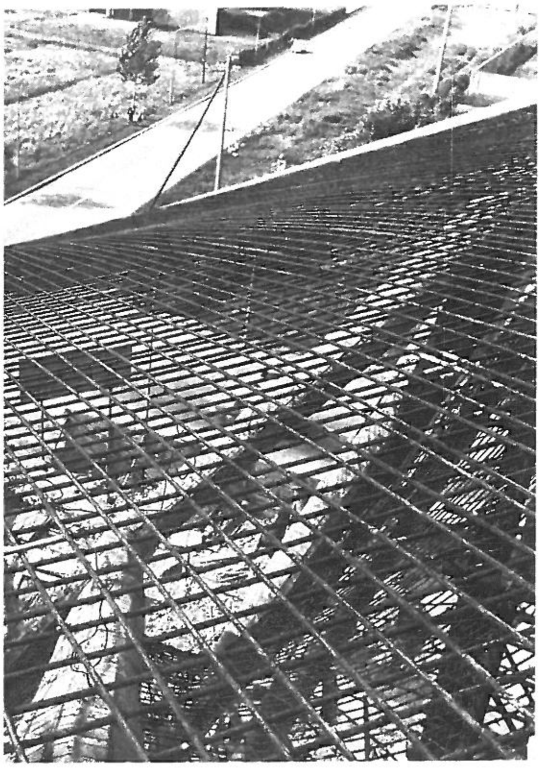


Fig. 26. The frame before casting.





Figs. 27-28. The reinforcing bars placed after the completion of the frame.

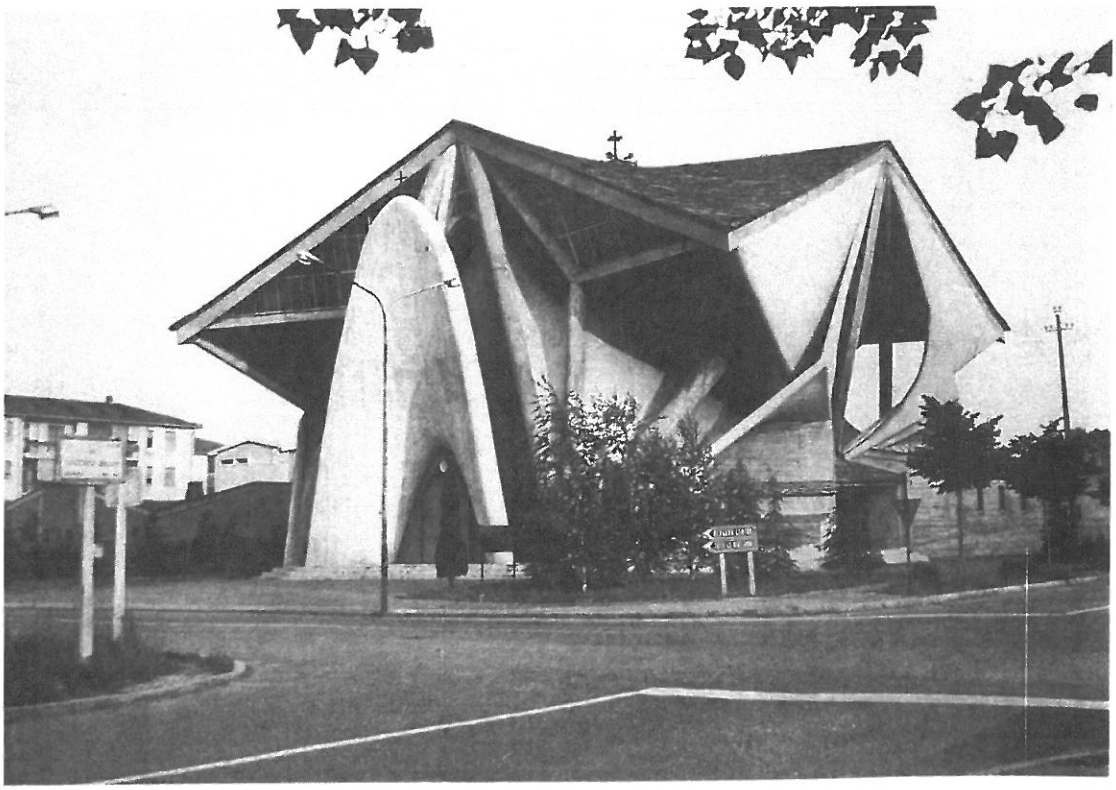


Fig. 29. Longuelo Church after completion.

Problems, changes and present status

Throughout the years there were several problems which required some restoration work. For instance, the construction of the roof was quite poor despite the use of slate, and for this reason in 1986 after an exceptional snowfall it had to be completely replaced. The new one was made of copper, and the work was directed by the architect Giovanni De Vecchi with a total cost of about 700 000 Italian liras, a hugely demanding cost. By that time, the structure, both frame and shells, appeared to be in working order.

Due to a limited budget only some parts of the exterior were rendered, in a grey tone which is very similar to concrete in colour, reducing the difference between the painted shells and the exposed concrete parts. Rendered parts are both the most visible and exposed to rainfall. However, the roof shells are large enough to cover the whole building entirely, and the very complex shape gave to Pizzigoni the possibility of hiding all the gutter pipes behind the frame (Fig. 30). That is probably why after about fifty years the building presents a uniform level of weathering, with the exception of the hall shell, which is completely uncovered by the roof and, as a consequence, quite damaged. Moreover, in some cases it was quite impossible to correctly cast the concrete over the shells as it is clear by looking at the rough surface finishing (Fig. 31). Nowadays, the structure itself is in a more critical condition, but comparable to most concrete building built in those days. Most problems are related to concrete cover of the reinforcing bars, while the shells were built with about 5 cm thick concrete cover, which is generally not problematic. The cover of the bars is so thin that in several parts of the structure it is now totally degraded, and the rods completely exposed (Fig. 31).

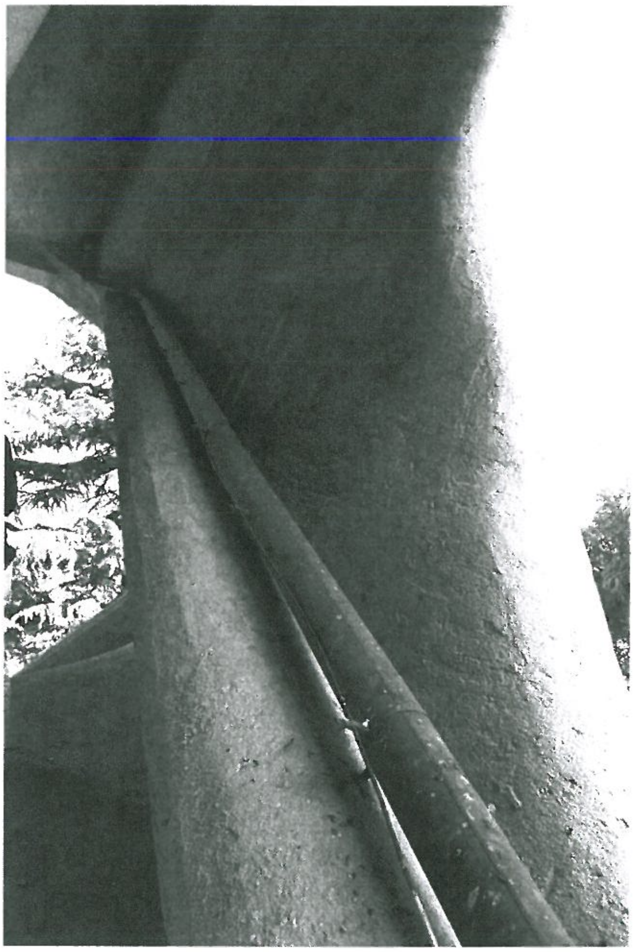


Fig. 30. Gutter pipes hidden in the structure.

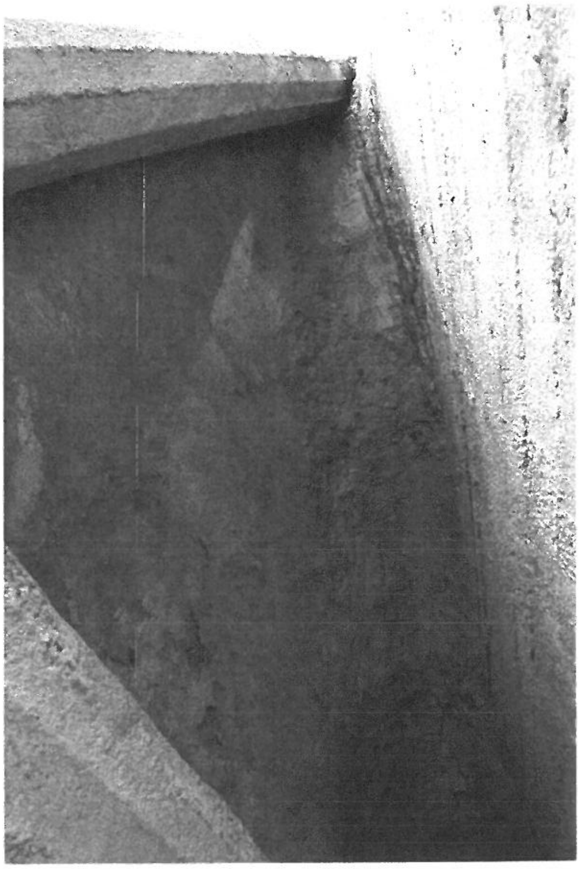


Fig. 31. Decay of the cover to reinforcing bars.

Further problems are related to the lack of ventilation in the church. The windows on the top of the building are fixed and therefore any kind of indoor climate regulation is impossible. Heating is now by warm air, but as the church is 18 m high, it is more effective at the top of the church than at ground level. A result is that it is completely useless and the ambient temperature is quite polar. These problems are intensified by the massive concrete floor, especially on the north side, where the thermal shocks are highest. A new restoration project has been planned already with Giovanni De Vecchi again as director.

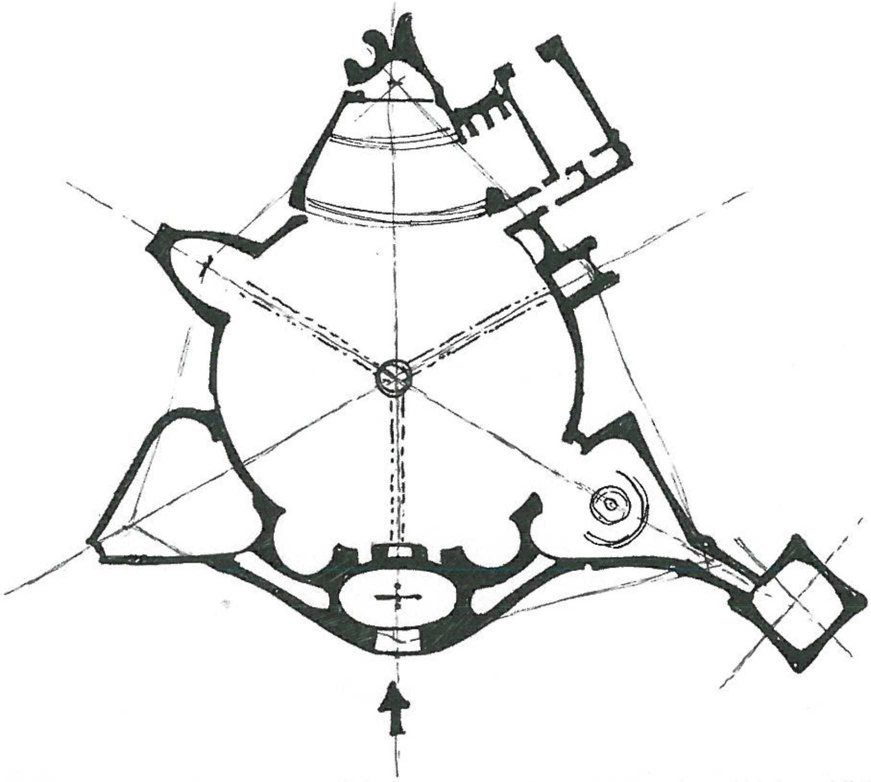
The church has undergone a number of changes, such as the addition of a baptismal font on the left side realized in rose marble by Attilio Pizzigoni, the replacement of existing windows, the very recent timber base for the altar and, above all, the main door, designed in art glass in 1992 by the painter Mino Marra made by Vincenzo Villa and Carlo Bertocchi. It is composed of several parts showing biblical episodes and, even if it is northward and cannot be seen against the sunlight, thus reducing its mystical impact, it is a very interesting piece of local sacred art. In fact, neither of these changes nor the modified seat arrangement has affected the spatiality of the church, but the presence of the cathedral glass enlivens the originally neutral ambience with a profusion of colours.

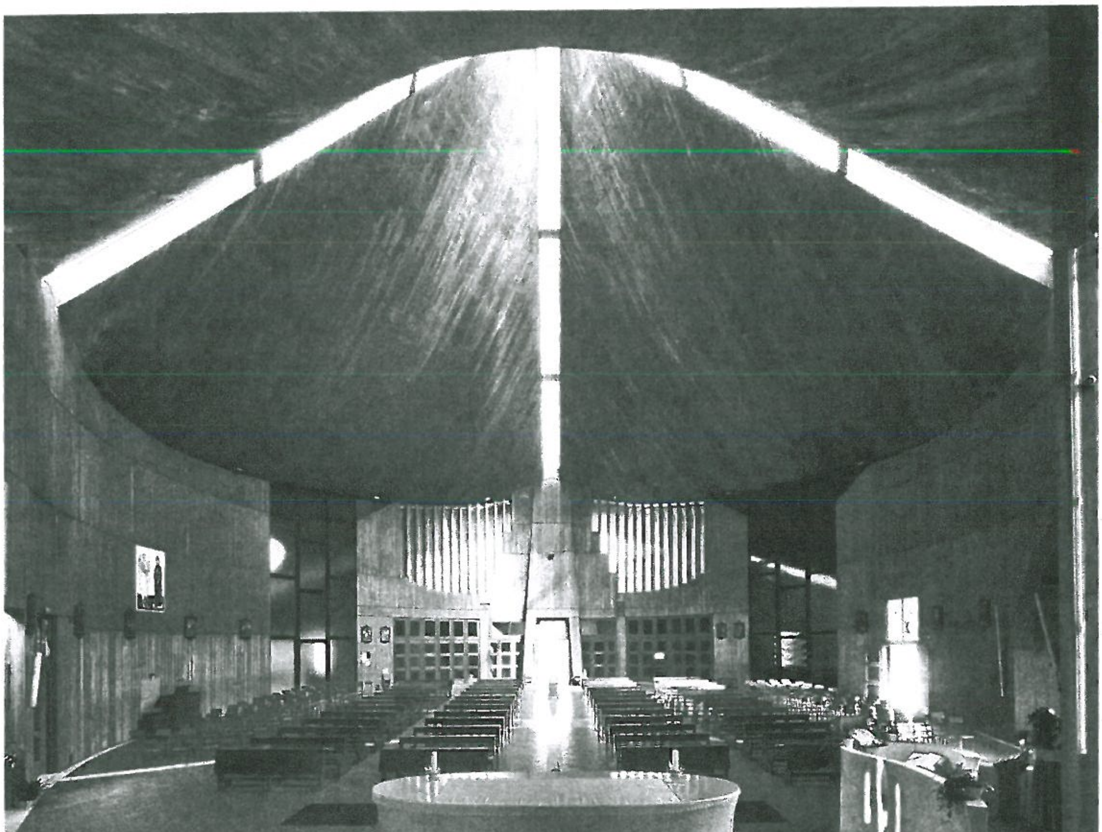
The influence of the church: two Bergamo examples

The church of Longuelo certainly made an impression among architects in Bergamo, even if we cannot claim that it succeeded in establishing a new aesthetic exploiting concrete shells. However it did have an influence on some other churches and chapels which were built a few years later. The Chapel of the Peace in Sotto il Monte, a town near Bergamo where the Pope Giovanni XXIII was born, was consecrated in 1976. It was designed by the architect Giovanni Muzio, a close friend of Pizzigoni. Its roof is composed of two symmetrical hypars and, compared to the Longuelo church, it is much simpler (Fig. 32). However, the two churches share the same technologies and construction methods, probably because their designers shared the same knowledge (and the same doubts) about concrete shells.

Fig. 32. Chapel of the Peace, Sotto il Monte, Bergamo (1976).

More impressive, the Church of St. Gregorio Barbarico in Monterosso, a district of Bergamo, was designed in 1965 and finished in 1971 by the architect Vittorio (Vito) Sonzogni and the engineer Enzo Lauletta. Vito Sonzogni was also a friend of Pizzigoni, and they worked together on the design of several buildings including some churches. This is a church with a centrical layout, very similar to that of Longuelo both in dimensions and in atmosphere. The plan is organized around a hexagonal design with a circular main hall and three main chapels alternating with three minor spaces (Fig. 33). The roof is composed of three symmetrical hypars held by massive concrete walls which create a number of niches; the hypars are quite independent, sharing only one point and leaving the wide open edges to be closed by windows. Even if the shape of the roof is simpler than that of the Longuelo church, the internal space is simply stunning due to the masterly use of light which enhances the formal composition and the material used. Also the bell tower is shaped by a sequence of hypars, which give it a pleasant, slender silhouette (Fig. 34). Everything is built in concrete, even the sculpted written inscription giving dedication and inauguration date sited at the entry of the church. From a purely structural point of view, it is clear that the building is not as interesting as the Longuelo church, but it is an important example of the cultural impact of Pizzigoni's work on the local community and of the application of concrete shells.





Figs. 33-34. San Gregorio Barbarico, Monterosso, Bergamo (1965-71).

Conclusion

The church of Longuelo is of the highest interest in the study of complex spatial structures. Pizzigoni was a local pioneer who took advantage of two main experiments with spatial structures: ambitious space frames, like domes by Buckminster Fuller or the Atomium, and complex concrete surfaces, like those used by Candela or Torroja. Both were used by Pizzigoni in conceiving this project, which became an extremely innovative structure.

The synergy between structure and form is obtained by means of an extreme conceptual simplification of a very complicated shape. Pizzigoni's approach to the structure is quite remarkable. It seems that his consciousness of frame behaviour was more intuitive than rational, as we see in reports where descriptions of the structure show several simplifications and ambiguities. His personal experience was not sufficient to fully control such a complex shape, and that is why the cost increased so much. The construction history of the church tells of a quite heroic approach, an interesting and problematic development and a pretty fortunate achievement, which led to a most remarkable building.

However, while with our historical and architectural view of the church we can be fascinated by its peculiarities, the church failed to obtain the praise of the community. Both local newspapers, such as *L'eco di Bergamo*, and the priesthood were quite critical of the building, mainly because of its odd shape.[30] Looking at the church it is evident that it also lacks a connection with the neighbouring context, standing in a corner of a field, facing a minor street without any churchyard. Being almost invisible because of the trees and inward-looking, it finally fails to become a real landmark, as churches are usually 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 merit of the church, appears to be fortuitous rather than intended. However, in spite of these critical considerations, the church of Longuelo is surely an utterly interesting case of an holistic approach to spatial structures, whose experimental character should be further investigated.

Acknowledgements

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Fig 22, 29: Parish Archive of Longuelo, Bergamo, Italy.

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26. De Santis, 'La chiesa dell'Immacolata', pp. 709-16.
27. In Italy the "Rbk" notation (which was expressed in Kg/cmq units) was replaced in 1982 with "Rck" expressed in N/mmq units; thus Rbk 500 concrete is now called Rck 50. These values relate to resistance to compression of the material, a fairly high value in the case of 500Kg/cmq.
28. PA, PIZ. A 210- 5.11- b/3.
29. PA, PIZ. A 210-5.11-b/4.
30. A compilation of articles of "I'Eco di Bergamo" about the Longuelo church can be found at the Parish Archive of Longuelo, Bergamo. Most are news stories, but often refer to real or supposed problems of the building.