# Experimental structures and reinforced concrete in church building in Italy: design and construction of three hyperbolic paraboloids (1961-68)

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## Introduction

In the second half of the twentieth century, the experimental reinforced concrete structure was the protagonist of the international architectural research of the late modern movement. In this context, the church building, with the inner need to cover spaces with medium and large spans, became a project theme that was particularly suited to the development of new ‘structural figures’. Of these, the form-resistant structural elements – folded slabs, thin vaults, hyperbolic paraboloids – became the subject of fervent experimentation.

In Italy, between 1952 and 1962, two special national laws were dedicated to public funding for the construction of church buildings, contributing to the construction of a large number of new works. In the national economic and productive horizon of reinforced concrete construction, the contemporary international rise of Italian engineering [1] and the liturgical renewal introduced by the Second Vatican Council (1962-65) [2], supported a timely structural experimentation extended to the construction of new churches throughout the country.

Investigating this phenomenon in the construction history field, starting from the recent monographic contributions [3], allows to integrate the studies already conducted in the history of Italian architecture [4], with the aim of recognising and disseminating the construction and technical characteristics of a fragile patrimony of experimental reinforced concrete structures, while also making a contribution to the study of Italian structural architecture in the wider international debate. The methodological approach consists of the reconstruction of the procedural and normative framework concerning ecclesiastical buildings (1952-1985) and the construction and technical characteristics of the single works (case studies), by analysis of the literature of the time and the archive sources. In particular, for the reconstruction of the regulatory and procedural framework, the study is based on the documentation of the Archives of the Pontificia Commissione Centrale per l’Arte Sacra in Italia (Pontifical Central Commission for Sacred Art in Italy - PCCASI), stored in the Vatican Apostolic Archives [5], accompanied by the magazine Fede e Arte (Faith and Art), its media outlet. The analysis of the single works is based on the primary sources of the archives of the architects, engineers and local dioceses, supplemented by on-site investigations.

This essay presents the case study of three churches designed by architect Vito Sonzogni (1924-2017) in collaboration with engineer Enzo Lauletta (1927-71) for the diocese of Bergamo and characterised by hypar roofs made of reinforced concrete. Based on the documentation stored in the private archive of Sonzogni, supplemented by the literature of the time, it was possible to reconstruct the design and construction process of the three works.

## A state plan for churches of “public utility”

On 18 December 1952, Law “State contribution to the construction of new churches” no. 2522 was published [6]: according to the provision, a loan granted by the Ministry of Public Works covered the purchase of land and the construction of new churches and buildings used for pastoral ministries. Considered works of public utility, the buildings were supported with the financing of 8 billion lire for the 1952-53 financial years. The law also ratified the role of an advisory and executive body of the Vatican, the Pontifical Central Commission for Sacred Art in Italy (PCCASI), for the verification and approval, on a technical and aesthetic level, of the projects covered by the funding in accordance with liturgical and sacred art precepts [7]. After the enactment of the law, requests were not long in coming: the projects for the construction of new churches, already financed by the fundraising from the communities of the faithful, spilled over into the applications for funding; between 1952 and 1961, the PCCASI received from all the dioceses throughout the country more than 3,400 case files for the preliminary approval of the projects, drawn up by engineers and architects directly appointed by the diocesan ordinaries and already approved by the Commissions for Art Sacred of the local dioceses.

On 18 April 1962, following the first ten years of work, new law no. 168 – "New regulations relating to the construction and reconstruction of religious buildings" [8]- integrated the first provision, consolidating and ordering the programme of works for the following decade: the list of works to be admitted to the contribution was drawn up annually by the Ministry of Public Works on the proposal of the PCCASI, while the share of expenditure was established by the Ministry, in relation to the number of parishioners. To obtain the loans, the procedure followed the one already established by law no. 2522 of 1952 [9], with the addition of the supervision of the Civil Engineers on the execution of the structural works and the assumption, by the State, of the testing costs. Finally, for the financial coverage of the grant, which would be disbursed according to a new framework that provided for constant lots, for 35 years to the extent of 4% of the eligible expenditure, the ten-year plan (1961-71) was approved, committing 350 million lire for the first year. Between 1962 and 1985, the year in which Law 168/1962 was repealed with the ratification of the new agreements between Church and State, the PCCASI received over 4,300 case files [10]. For the entire period of activity of the PCCASI, the projects of the remaining works, which had been excluded from financing or funded with funds from the congregation or local dioceses, were, however, examined by the territorial Commissions for verification of compliance with the liturgical and sacred art precepts, in constant dialogue with PCCASI [11].

The regulatory requirements excluded all finishing works and the decorative additions from financing so the designers concentrated on the definition of structures that interpreted, in the rustic style, the precepts of liturgical spatiality and sacred art. The PCCASI or the Commissions of the local dioceses, commented on and directed the principles of construction towards "noble and monumental solutions", using a "lively structural concept" [12]. Ideas certainly influenced by the contemporary international recognition of the rise of Italian engineering.

While, in 1956, the architect Saverio Muratori wrote, starting the debate in the magazine *Fede e Arte* [13], "the church is the architectural organism most interested in the current development of technologies, the theme that can impersonate it and express it" [14], the projects that were examined by the PCCASI in 1950s and 1960s were an objective testimony of this.

## Three hypars for the diocese of Bergamo (1961-1968)

In the inspiring context of this "lively structural concept" [15], the design collaboration between architect Vito Sonzogni (1924-2017) and engineer Enzo Lauletta (1927-71) developed between 1961-68. The professional partnership led to the construction of three churches - the Sanctuary of Maria SS. Regina in Zogno (1962-66), San Giacomo in Castro (1965-69), and S. Gregorio Barbarigo in Monterosso (1967-71) - characterised by challenging reinforced concrete structures.

### *Sanctuary of Maria SS. Regina in Zogno (1962-66)*

In 1958, the parish priest of Zogno started raising funds from the parishioners for the construction of a new church for the small town, the Sanctuary of Maria SS. Regina. Architect Sonzogni was involved in the project design and in 1960, after the fundraising effort, 50 million lire were allocated: Sonzogni had meanwhile drawn up various proposals for the construction of the church based on an entirely reinforced concrete building characterised by expressive load-bearing structures.

The executive project was developed between 1961 and 1962: based on Sonzogni's preliminary project. Engineer Lauletta [16], then employed at the ISMES *Istituto Sperimentale Modelli e Struttur*e (Experimental Institute for Models and Structures) in Bergamo [17], took charge of the calculation of the structure. The collaboration between the two designers was fundamental for the design of the definitive solution: the church, in the executive design phase, passed from a volume characterised by curvilinear partitions and a free-form curved roof, to a rhomboid volume covered by a hyperbolic paraboloids thin shell (Fig.1). The structural drawings, developed by Lauletta between 1961 and 1962, testified to the introduction of the hypar in the geometry of the project: it featured a rhomboid-shaped plan (whose diagonals measured respectively 35 and 26 metres) and projected beyond the perimeter of the building. The shell was only 6 cm thick, with sturdy edge beams; its horizontal thrust on the transverse diagonal, was absorbed by the bell tower, on the left hand side, and the curvilinear walls, on the right.

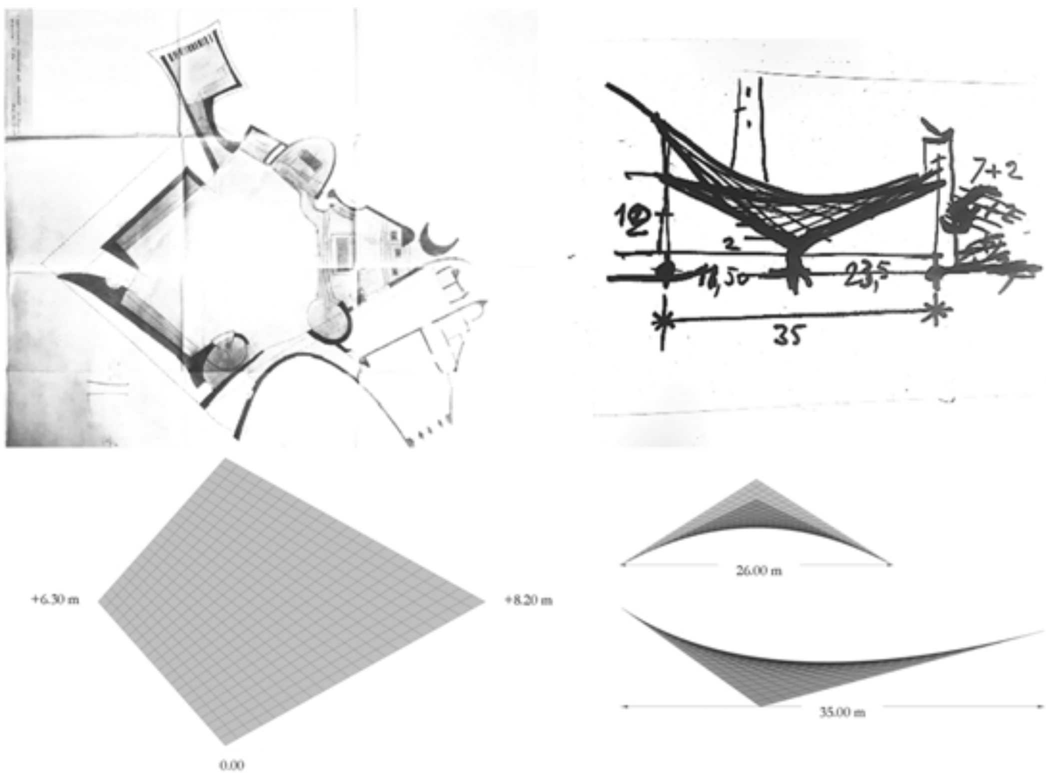


*Figure 1: Plan and sketch of the Zogno church, 1961 (courtesy of Laura Sonzogni) and 3D sketch of the hypar geometry*

If, as Lauletta affirmed, the hyperbolic paraboloid was easy to construct for small spans and did not even present any calculation difficulties, in the case of roofs with more demanding spans, such as those of the church of Zogno, “new phenomena came to the fore and sometimes dramatically with extensive cracks and even with collapses” [18]: in these cases, in fact, the edge beams could not be considered just simple struts, since they were subject to bending and torsion, and the shell itself had to be checked for the danger of buckling. The recourse to the physical model in the calculation of the structure, given Lauletta's professional position at ISMES, was the next step in the design process: as anticipated in the technical report – "fortunately the use of physical models allowed us to study these phenomena and deal with their dangers" [19] - experimentation on the physical model gave the opportunity to closely examine the calculation of thin shells, a research topic to which Lauletta had been dedicating himself since 1961 [20], in the context of the broader international debate [21].

A scale model, reproducing the geometry of the Zogno shell in 1:25 scale, was built in the ISMES laboratories in September 1963 and Lauletta himself carried out the tests.

As shown in Figure 2, the load equipment consisted of rubber dynamometric rings bound at one end to the structure and anchored, on the opposite side, to a rigid floor that, once lowered with the aid of hydraulic jacks, created the tension and, therefore, the application of the load [22]. During the tests, carried out on 25 September, the measurements were carried out with mechanical strain gauges and flexometers. The extensive tests were carried out by supporting the vault at five points, detecting the sags obtained when applying the various loads, up to the collapse of the structure with a load of 1480 $kg/m^2$ [23].

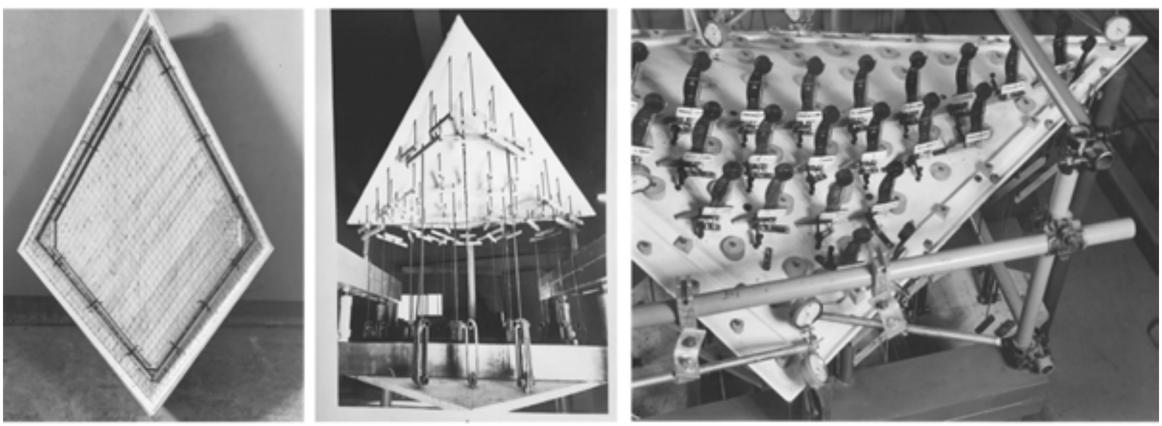

*Figure 2: Structural model of the Zogno hypar, tested by Lauletta at ISMES in Bergamo, 1963 (courtesy Laura Sonzogni)*

The checks on the model were then used to redefine the size and layout of the armature, shell and edge beams.

Work started at the construction site of the Sanctuary on 30 June 1962. The contractor for the work was the company belonging to Pietro Sonzogni, Vito's father, whose premises were located on the land adjacent to the land where the sanctuary was to be built: Pietro's company was an established local entrepreneurial business specialising in the installation of electrification poles but had no experience in reinforced concrete construction. Yet, in May 1966, when the Sanctuary had just been finished, the successful execution of the ecclesiastical structure also made the news in the local newspapers, which praised master builder Sonzogni for his "incredible skills in the use of this material" [24].

The construction of the Sanctuary was achieved by using ingenious construction site techniques : the use of the Innocenti tube and coupler [25] scaffolding made it possible to construct the hyperbolic paraboloid as a ruled surface, for which the structure received international recognition. Instead of the traditional wooden scaffolding usually used for the construction of the formwork of the ruled surfaces a structure of tube and coupler was used to support the casting of the hypar (Fig. 3). As evidenced by the evocative photographs of the construction site, the tubes, set-up on the ruled surface generatrix, allowed the arrangement of  wooden boards to support the casting of the shell. The boards were arranged crosswise in order to obtain, as Sonzogni intended, an intrados surface “decorated by the traces of the thin and flexible boards” [26]. The shell was then coated in copper with an artisanal cladding where the gutter channels were integrated (Fig. 4).

*Figure 3: Zogno church under construction: the set-up of the Innocenti tubes on the ruled surface of the hypar and the arrangement of the wooden boards to support the cast of the shell, 1962 (courtesy Laura Sonzogni)*

*Figure 4: Interior view of the Zogno church in 1963 (courtesy of Laura Sonzogni) and the Zogno church in July 2020 (pictures by Ilaria Giannetti)*

*San Giacomo in Castro (1965-69)*

Sonzogni started the design of the Church of San Giacomo in Castro in 1965, during the construction of the Sanctuary in Zogno. The State contribution was required for the construction: the project dossier, initially sent for inspection to the New Churches Committee of Bergamo, on 30 October, was then forwarded to the PCCASI, which issued its favourable opinion approving the financing of 30 million for the construction of the building. In a note dated 2 April 1965, the Ministry of Public Works approved expenditure for the construction of the rustic "building of worship to be erected in the municipality of Castro in the area already owned by the parish" [27].

The building has an elliptical layout, on whose minor axis there is a parabolic curve that included the altar, the cathedra and the tabernacle, while access to the church is on the opposite side, from a large covered atrium, on the sides of which are two chapels, with an independent access. The building is made entirely of exposed reinforced concrete. The roof consists of a double-curved shell that, profiled on a hyperbolic paraboloids ruled surface, covers the space of the hall, the altar and part of the atrium, with challenging spans of 36.75 and 38 metres, on the two diagonals (Fig. 5). The shell, only 6 cm thick, is lined with copper plates.

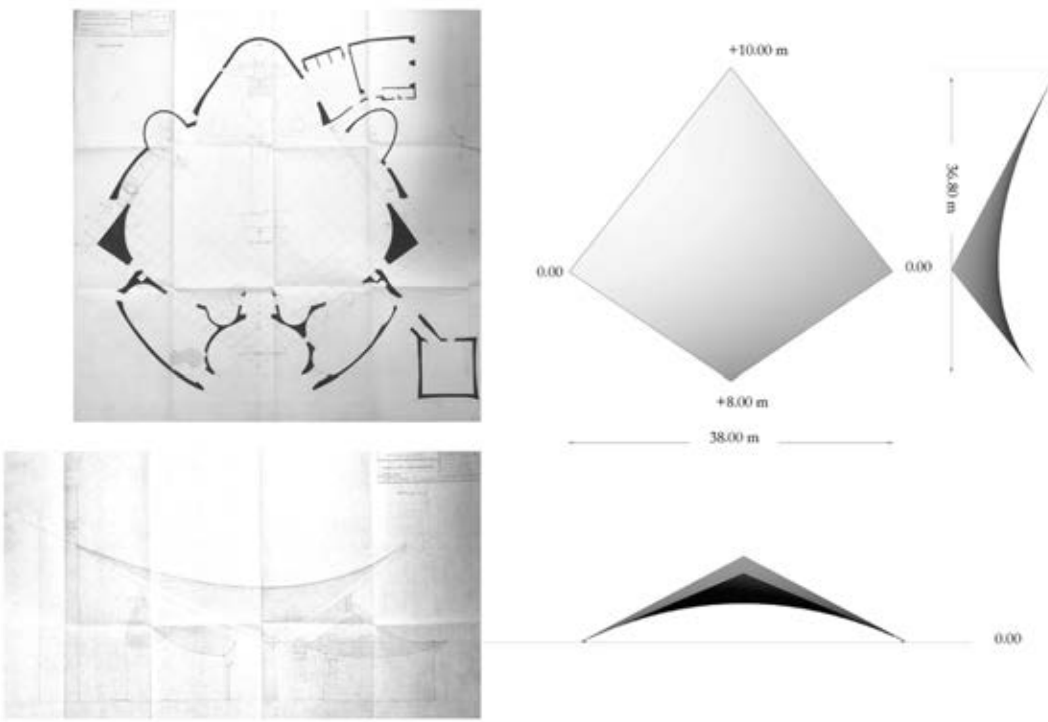


*Figure 5: Sonzogni's drawing of the Castro church, 1966 (courtesy Laura Sonzogni), 3D sketches of the hypar geometry*

Lauletta signed the structural design on 1 July 1966, sending a copy to Sonzogni on the 18th of the same month. The report contained the criteria for calculating the shell: the procedure adopted was based on the 'membrane theory of shells', disseminated by the literature of the time and studied by Lauletta himself [28], applying it to a hypar model characterised by a geometry that was simpler than that of Castro. The results were integrated with those of the tests carried out on the model of the roof of Zogno.

The hypar presented in the calculation report was, contrary to Castro's, a symmetrical ‘warped parallelogram’ (described by the equation z=xy/c [29]) with 25 m diagonals and, in the model, the edge beams were considered as four simple struts loaded axially. The external load (P) was divided between “arches and cables” (Fig. 6).

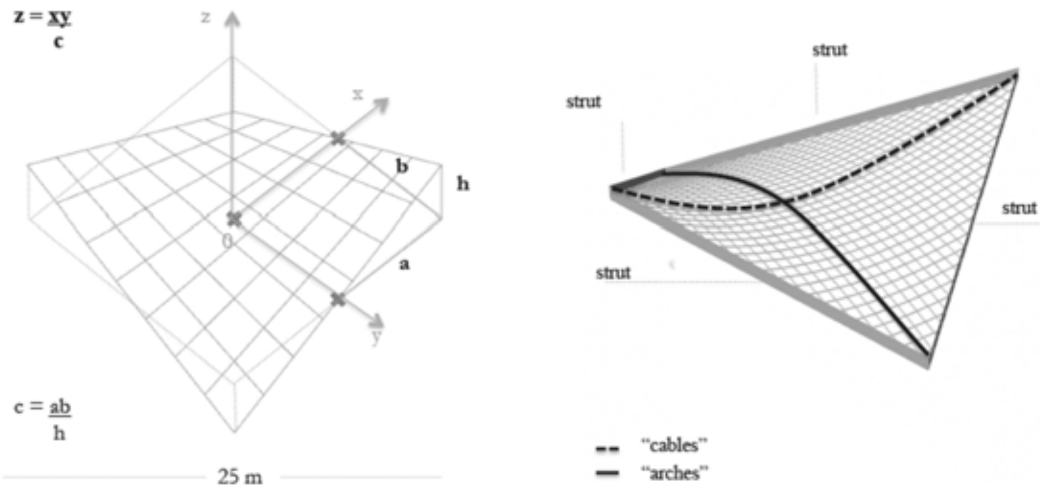


*Figure 6: Sketches of the hypar geometry adopted by Lauletta in the calculation for the Castro’s shell, 1966*

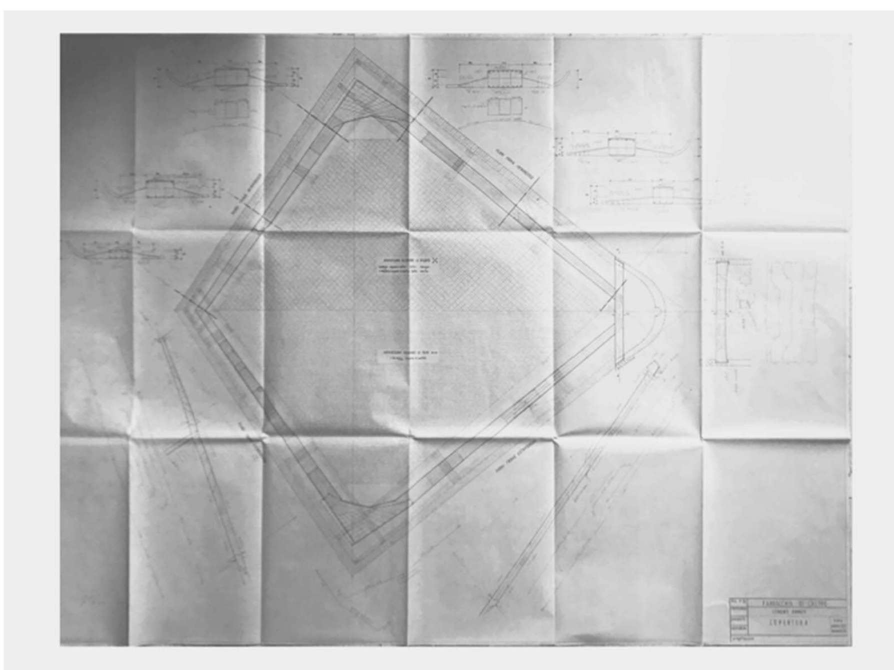

*Figure 7: Execution drawing of the Castro shell, 1966 (courtesy Laura Sonzogni), sketches of the warped surface with points coordinates adopted for the shell scaffolding and formworks set up*

Therefore, considering the maximum stresses of the materials, the vault is reinforced with Φ 8 irons placed every 60 cm, on the long side of the warped parallelogram, every 30 cm on the short side and every 20 cm following the warping of the “cables”, while to counteract the horizontal forces of the hypar a chain was inserted, in the foundation, at the location of the minor diagonal (Fig. 7) [30].

As at Zogno, the edge beams were subjected not only to axial actions but also to bending, shearing and torsion. The results of the tests on the model were used for analysis and verification of the edge beams which have a tapered section of a constant height of 50 cm and a variable width, from 60 cm to 1 metre at the corner pillars, on the smaller diagonal.

To generate the execution hypar geometry, the ruled line is drawn by dividing the two opposite sides of a skewed quadrilateral, whose vertices on the longitudinal diagonal, were respectively 8 and 10 metres high, in 21 points and drawing the segments that joined them (Fig. 7); the operation was repeated starting from the opposite sides of the same quadrilateral, building a quadrangular grid and thereby identifying the heights of 484 points that would guide the construction of the scaffolding and the support planking for the casting.

The F.lli Pasinetti company, entrusted with the construction of the work following the tender-competition awarded on 12 November 1966, reported the characteristics of the reinforced concrete structure of the church to the Prefecture of Bergamo on 2 February. The construction site opened immediately after. The shell was cast on 29 April 1968 (Fig. 8): the scaffolding, similar to that of Zogno, was made of Innocenti tubes arranged along the short side of the warped parallelogram. The ribs were removed on 8 and 9 May. The church was consecrated on 14 June 1969, following the waterproofing of the roof with the installation of the copper mantle.

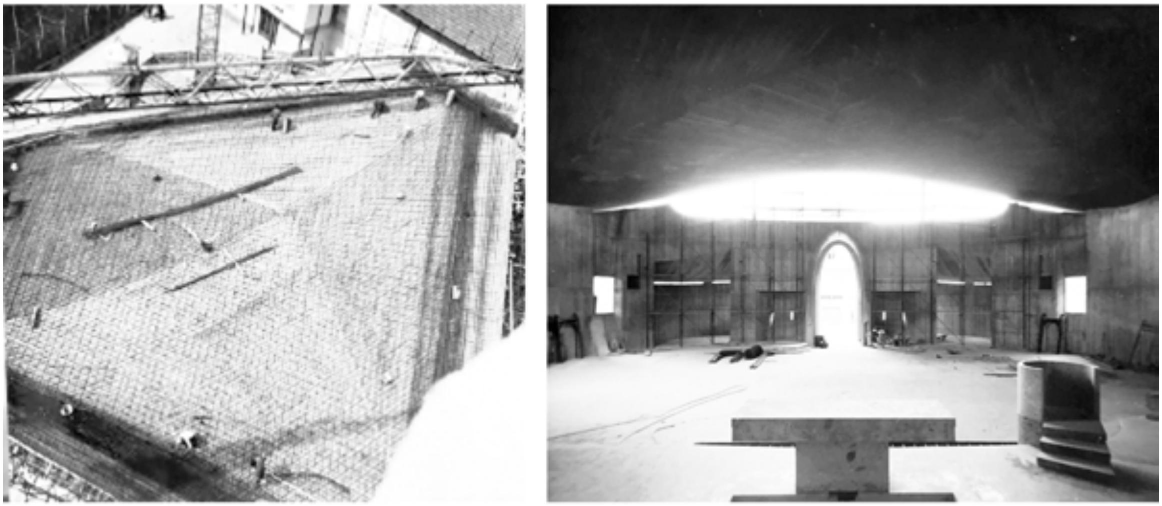

*Figure 8: The Castro churchs hypar under construction and inner view of the church hall, 1968 (courtesy of Laura Sonzogni)*

## *S. Gregorio Barbarigo in the Monterosso district in Bergamo (1967-71)*

Sonzogni and Lauletta's project for the new suburban parish in the Monterosso district of Bergamo started in 1967: the proposal was approved by the Bergamo Sacred Art Commission on 18 January. The church, again with a central system and made entirely in exposed reinforced concrete, has a triangular layout that is covered by juxtaposing three rhomboid-shaped hypars.

The three hypars, 12 cm thick, rest on two sides on the curvilinear perimeter walls, remaining independent (Fig. 9): between the three canopies, evocative interstitial skylights allow the passage of the zenithal light. At the transversal diagonals of the three shells, sturdy vertical supports counteract the forces, functioning as real buttresses, assisted by a system of chains placed in the foundation (Fig. 9).

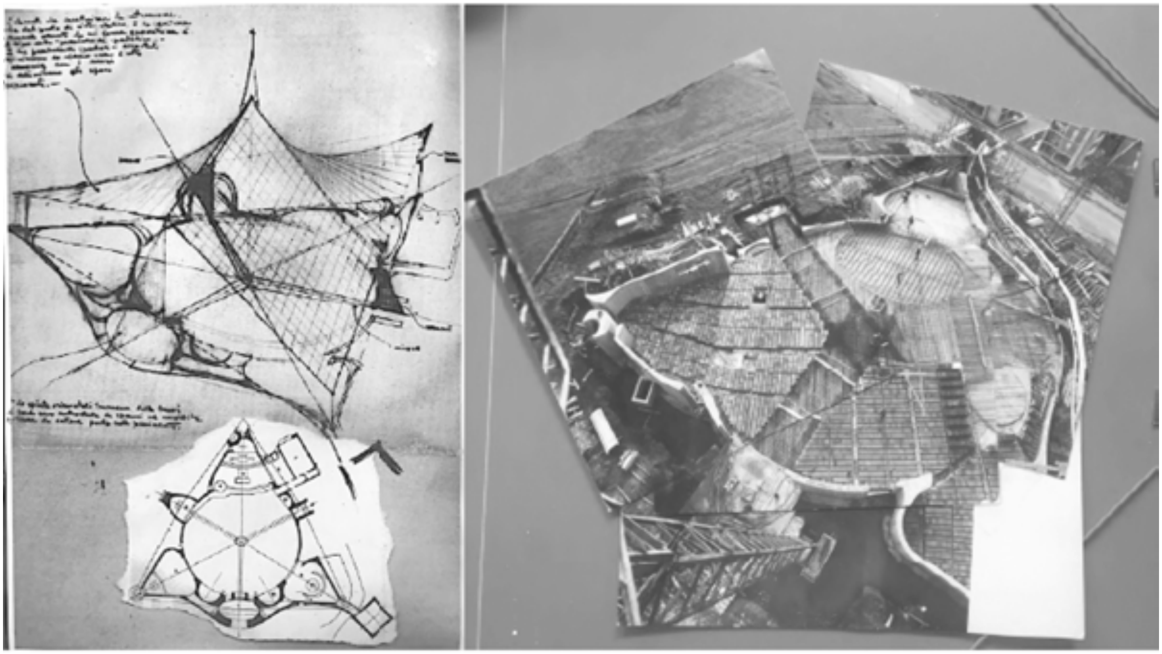

*Figure 9: Sonzogni's sketch of the San Gregorio's and the church under construction, 1967 (courtesy Laura Sonzogni)*

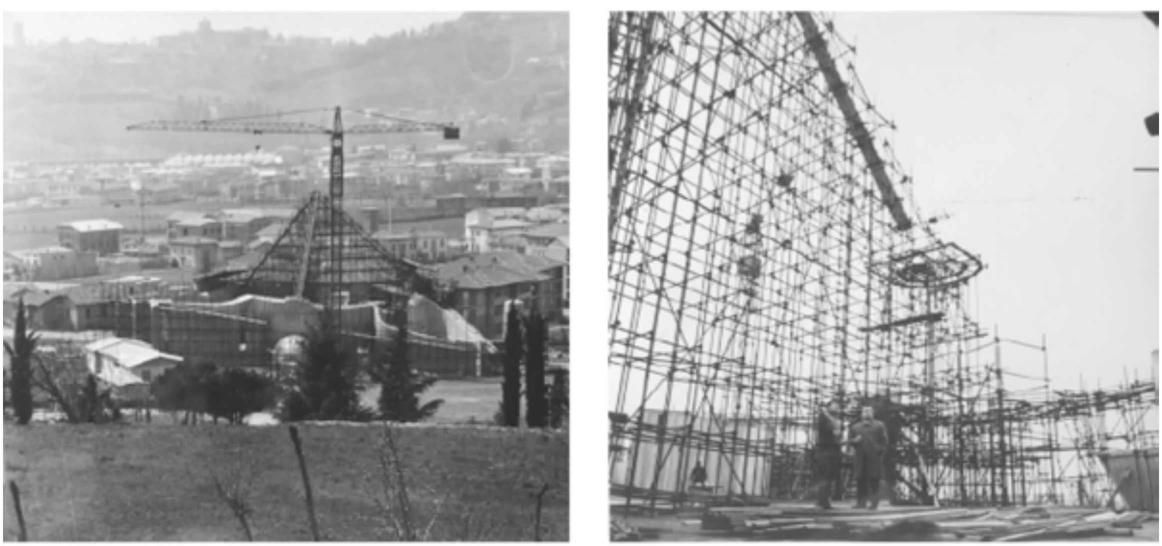

*Figure 10: San Gregorio's and the church under construction, 1967 (courtesy Laura Sonzogni)*

The construction site opened on 18 June 1967. The works were awarded, following a tender competition, to the Augusto Adobati company. In 1970, after the completion of the wall structure, the company left the site: the shell had not yet been built. To save the new structure from ruin, the company of Pietro Sonzogni accepted the contract for the completion of the works on 6 August 1970. As in Zogno, the three hypars were then cast "tracing in negative the geometry of the shell through the fitting of the Innocenti tubes along the ruled surface" (Fig. 10), while a more costly arrangement was agreed, "for the use of flexible and planed boards" [31] to support the castings, in order to decorate the shell with their imprint. The construction site closed on 18 September 1971.

## Conclusions

After the Second World War in Italy, the construction, supported by state aid, of the new "mantle of churches in the country" [32] involved engineers and architects in a design and construction experiments throughout the country. There were numerous projects for new churches that focused on plastic-figurative structural inventions, arising from the plasticity of reinforced concrete.

In the 1950s and 1960s, the relationship between the design theme of the intermediate span covering and the renewed expressive needs of the place of worship, suggested and governed by the control of the ecclesiastical bodies, and taking into consideration the precepts of the renewed liturgy of the Second Vatican Council, was resolved in the invention of some structural icons, which spread throughout the country making a capillary (and still relatively unexplored) contribution to the 'structuralist' trends that developed in the maturity of the modern movement [33].

As part of this extensive collective experimentation, this study focuses on the churches built by Sonzogni and Lauletta for the diocese of Bergamo as an original contribution to the design and construction of the hyperbolic parabolic in the second half of the 20th century.

In this sense, the study highlights the characteristics of the experiments of Sonzogni and Lauletta, in comparison with the international experiences on this successful structural element [34], through the most affirmed trends of the Italian School of Engineering [35]: physical modelling, ingenious constructive solutions within the artisan construction site and artistic reflection on structural forms, through a close collaboration between the architect and the engineer.

In this sense, the collaboration between the two was crucial to the success of the project ("I needed Science and I went to get it from Lauletta", wrote Sonzogni [36]). The joint reflection of the two designers deeply involved the principles of the tectonic conception, from the ability to make room for structural forms to the ornamental qualities of the resistant material. The hypar embodied, in the three churches, both the spatial device of the renewed demands of worship expressed by the Second Vatican Council ("beauty is to be sought in the balance between the sense of daring and that of monumentality, a formula offered more by science than by art" [37]) and an ornamental expression through an appreciation of the aesthetic qualities of reinforced concrete ("the shell decorated inside by the imprint of the wooden boards" [38]).

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