HEINZ ISLER: SHELLS FOR TWO CHURCHES

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ABSTRACT

This paper describes the concept, design and realisation of two churches where Heinz Isler (1926-2009) was responsible for the structural design and in one case also for the architectural concept. One example, the Heilig Geist Kirche (Holy Spirit Church) Lommiswil, near Solothurn, Switzerland (1967) includes, unusually for Isler, a "hypar" shell whilst the other, the "Steinkirche" of the Evangelische Kirchgemeinde in Cazis, Switzerland (1996), is derived directly from given natural forms.

Keywords: *Heinz Isler, Holy Spirit Church Lommiswil, hyperbolic paraboloid, Steinkirche Cazis, reinforced concrete shells*

1. INTRODUCTION

The Swiss engineer Heinz Isler (1926-2009) is best known for two quite different shell types which resulted from two of the form-finding methods he described in his significant paper "New Shapes for Shells," presented at the First Congress of the International Association for Shell Structures, held in Madrid in September 1959 [1, 2, 3]. These are the "bubble" shells, based on the form generated by inflation of a rubber membrane through a fixed template and the "free-form" shells resulting from the inversion of the form of a hanging membrane. The former was used predominantly for repetitive, standard shells for industrial and commercial buildings, whilst the latter were generally, but not exclusively, "one-off" shells such as the petrol station canopies at Deitingen Süd, constructed in 1968.

Nevertheless, Heinz Isler did not limit himself to these forms. In the first of the two churches described here, Heilig Geist Kirche (Holy Spirit Church) at Lommiswil (1967), he utilised the more commonly applied hyperbolic paraboloid ("hypar") – a shape more usually associated with the shells of Félix Candela (1910-1997) – although in this case Isler applied it to an irregular plan. While not the only "hypar" designed by Isler, this is the most notable. For the second church, the so-called "Steinkirche" of the Evangelische Kirchgemeinde in Cazis (1996), he worked with a form given by the architect – three linked shells derived from found natural objects.

2. HEILIG GEIST KIRCHE (HOLY SPIRIT CHURCH), LOMMISWIL, 1967

The Heilig Geist Kirche (Holy Spirit Church) at Lommiswil, near Solothurn, Switzerland [4, pp. 122-128], Figure 1, is an interesting case where Heinz Isler undertook his customary role as engineer but also shared the credit for the conceptual design with the architect, Roland Hanselmann from Olten.

2.1 Design concept

In the 1960s the congregation of the Lommiswil Church decided that they would commission a new church. Of the several schemes submitted by the architect Roland Hanselmann, most required the demolition of the earlier 14th century chapel, which sits upon a small rise adjacent to the new church (to the right in Figure 1), and its replacement with one of more modern design. However, in 1965, having seen Isler's recently completed Wyss Garden Centre shell, in Solothurn, the Lommiswil minister invited him to visit the site and give his opinion. As Heinz Isler told the story of his inspiration for the final concept, it came to him during the visit to the older chapel when his eyes were drawn to a single tree in a nearby hollow in the landscape. Walking towards the tree he commented that the

Figure 1: *The Heilig Geist Kirche (Holy Spirit Church), Lommiswil (1967) with the earlier 14th century church to the right. (Photograph: John Chilton)*

chapel was too valuable to destroy and gestured that the new church should perhaps be alongside it in that hollow.

Returning to the pastor's house he set to work with small twigs, thick knitting wool and children's modelling putty to create the concept model shown in Figure 2. The significance that Heinz Isler gave this model is demonstrated by the fact that it was retained and was still available to be photographed at his office almost 45 years later. The plan form was composed of linked spiral curves, the twigs defining a perimeter wall rising as it coiled towards the centre. On connecting the top of the twigs across the nave the interwoven wool generated a rough ruled saddle surface that was to become the basis of the final hyperbolic paraboloid roof form. The similarity between the concept and completed church can clearly be seen by comparing Figures 1 and 2. Through form and material (exposed and textured reinforced concrete) it was intended that the church would seem like a huge boulder dislodged from the Jura Mountains. However, there were several intermediate stages needed to move from the initial sketch model to the built form.

2.2 Sketch model to architectural design

During a 2011 visit to Heinz Isler's former office at Lyssachschachen, near Burgdorf, the design process was more fully revealed. There the model used to visualise the differential massing of the perimeter walls of the church could be seen – solid foam for the wall eventually constructed from in-situ reinforced concrete and thin wood strips to represent the separate pre-cast concrete elements, with their textured timber board finish, Figure 3.

Figure 2: *Concept model for Holy Spirit Church, Lommiswil (Photograph: John Chilton)*

The orientation of the final "hypar" surface was the result of further modelling processes. First a full "hypar" was tilted about the axis through the supports (the two low points) thereby raising one of the high points and lowering the other. Subsequently, the left support was raised, rotating the surface about an axis through the lower right support and one of the (now lowered) original high points.

Figure 3: *Architectural massing model for Holy Spirit Church, Lommiswil (Photograph: John Chilton)*

Heinz Isler's rather indistinct sketches – deteriorated due to exposure to sunlight over many years - showing the relative co-ordinates of the high and low points during this process are shown in Figure 4. The sketch on the left shows the relative co-ordinates after the first rotation, listed clockwise from the bottom (+13 = +8, +5 = 0, +55 = +50 and +5 = 0). That on the right shows the final relative positions after the second rotation, again listed clockwise from the bottom (+13, +10, +55 and 0). The segment of this surface that was used for the Lommiswil church roof is the resin form superimposed on the white area in Figure 5.

Isler's manipulation of the basic "hypar" surface is reminiscent of Candela's in the church San José Obrero, Monterrey, México, constructed in 1959 (architect Fernando Lopez Carmona). As an admirer of Candela's work since the 1960s when, in Zürich, he came across a book of his shells, Isler was definitely aware of that *tour de force* of hypar surfaces in church architecture. In what is perhaps the most extensive text he published about his own work, in the magazine *Arcus* in 1992 [5], Isler selected it as one of his two favourite works of Candela, alongside the Los Manantiales Restaurant Pavilion in Xochimilco. For the church in Monterrey two opposed tilted hypars form the main volume. Isler's undoubted enthusiasm for that work may well have influenced him to take a tilted hypar as generator for the Lommiswil shell.

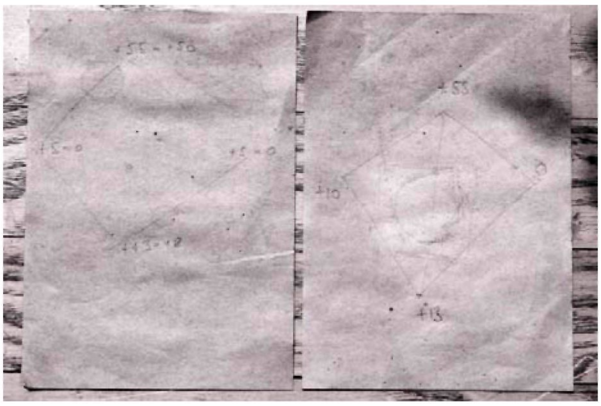

Figure 4: *Notes in Heinz Isler's hand noting co-ordinates of tilted and rotated "hypar" surface (Photograph: John Chilton)*

Figure 5: *Tilted and rotated "hypar" surface with segment used for roof of the Holy Spirit Church, Lommiswil (Photograph: John Chilton)*

2.3 Proving the form

Apart from its plan shape and tilt, the roof of the Holy Spirit Church, Lommiswil, is a relatively conventional hyperbolic paraboloid form with maximum plan dimensions of 26 x 28.5m. However, because of the spiral (rather than more conventional square or rectangular) plan and the monolithic connection of roof and wall structures,

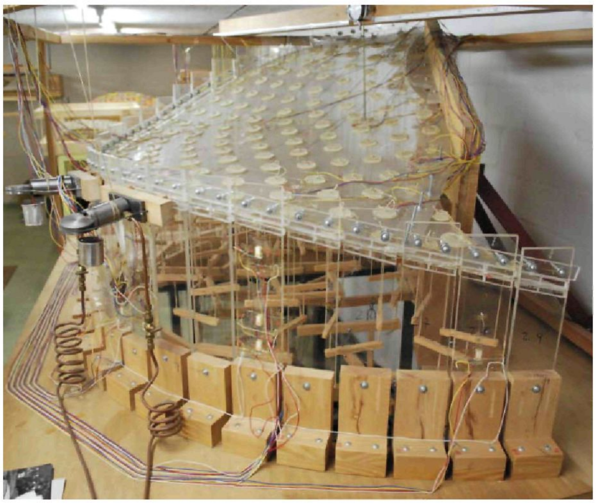

Figure 6: The Plexiglas model used for the evaluation of structural behaviour of the Holy Spirit Church, Lommiswil. (Photograph: John Chilton)

Heinz Isler drew upon his tried and tested methods to explore and verify its structural behaviour.

Until 2011 when it is to move to ETH Zürich, the Plexiglas model that he constructed – of the whole church structure, not just the roof – resided in the basement laboratory (sadly, unused since his death) of his office in Lyssachschachen, near Burgdorf, Switzerland, Figure 6.

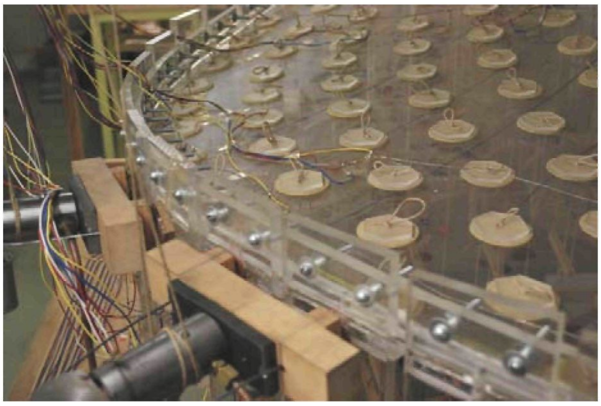

Figure 7: Detail of the Plexiglas model showing jacking, load points and instrumentation. The pre-stressing "cables" can also be seen. (Photograph: John Chilton)

The majority of Isler's shells are specifically designed to remain in compression under all load conditions, but in the case of the hyperbolic paraboloid both tension and compression stresses normally occur. To overcome the adverse effects of the tension stresses Isler applied a pre-stress through the shell surface by post-tensioning using eight cables between the wall tops as shown on the roof plan, Figure 8, and in the detailed section, Figure 9. This he simulated in the workshop model to satisfy himself of the stability and durability of his design, Figure 7. As can be seen in Figure 6, as usual for Isler's experimental technique, the roof loads were applied by means of small wooden discs distributed evenly over the surface to simulate uniformly distributed load. In turn these were connected to a hanging network of timber spreader bars and strings in such a way that the distributed load could be applied with a single weight or hydraulic jack.

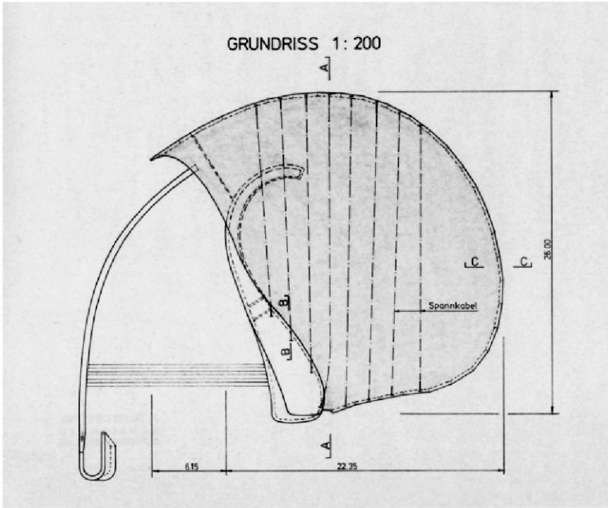

Figure 8: Roof plan of the Holy Spirit Church, Lommiswil, showing the disposition of eight pre-stressing cables. (Drawing: © Heinz Isler)

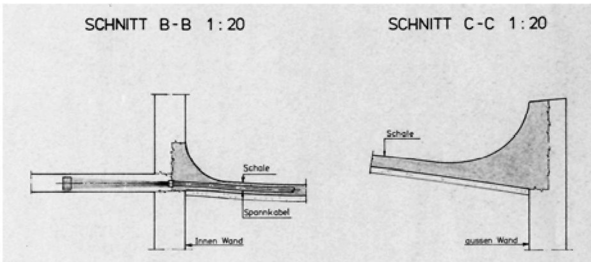

Figure 9: Detailed section of the shell showing the application of pre-stressing (Section B-B) and connection with the pre-cast perimeter wall (Section C-C). (Drawing: © Heinz Isler)

The pre-stressing force was applied by small hydraulic jacks, as can be seen in Figure 7, where the modelled pre-stressing cables can also be discerned. This arrangement allowed vertical, horizontal and pre-stressing loads to be applied in appropriate combinations, simulating the shell self-weight, full snow load, partial snow, etc. Uplift

Figure 10: *Detail of the perimeter wall showing the sockets for pre-stressing cables (upper circles) and large circular window. (Photograph: John Chilton)*

Figure 11: *Entrance of the Holy Spirit Church, Lommiswil, with almost imperceptible steel prop to minimise edge thickening. (Photograph: © Heinz Isler)*

loads induced by the wind were assessed by appropriate factoring and reversing the stresses (derived from electrical strain gauges attached to the model surface) resulting from downward loads. It may also be noted in Figure 6 that the individual precast concrete wall units were modelled as separate components, including the large circular window seen in Figure 10.

2.4 Entrance cantilever

To the right of the main entrance the boldly textured *in-situ* portion of the perimeter concrete wall drops steeply towards the main entrance door. Exploiting the difference in level, the shell, which for the most part joins and is fully supported by the perimeter wall below its parapet, is allowed to oversail the wall. This provides the architectural feature of a glazed panel above the door, filling the space between the underside of the shell and top of the inward spiralling wall. It also creates a protective canopy over the main door. For this reason the two structural elements (shell and wall) have different plan forms, see Figure 8. However, this architectural device complicated the structure for Isler as it broke the continuity of the ring beam around the wall top, which constrained the shell. Originally, only 100mm thick, the shell was intended to be unsupported by the in-situ wall over this length.

However, on testing the structural model, Isler found that the compression forces exceeded the buckling capacity of the shell edge, requiring edge thickening. To limit the size of that thickening a slender steel restraint/prop was introduced at the point where the edge of the shell crosses the line of the wall below, thereby allowing the architect's concept to be realised and the structural requirements of the engineer to be satisfied.

This prop is thicker than the mullions within the glazing and, being offset from the plane of the glazing, does not normally coincide visually with a mullion location. Nevertheless, as can be seen in Figure 11, the additional support is barely noticeable, being overshadowed by the shell. The view of both engineer and architect was that the introduction of the prop had a less detrimental effect on the aesthetics of the building than would have been the case with a thicker shell edge.

2.5 Construction

To create the spiral form economically, the parts of the external wall where the radius of curvature is larger are of full-height precast concrete panels. These are of increasing height towards the centre of the spiral. The remainder is in-situ concrete with a highly-textured finish. The shell roof is connected monolithically to both the precast and in-situ wall elements. Together with the edge stiffening over the main entrance door this creates a stiffening ring for the perimeter of the shell. Pre-stressing was applied between the encompassing walls in one direction, across a wide area of the shell (see Figures 8, 9 and 10), to provide an initial pre-compression of the thin shell surface. As in many of Isler's shells the completed roof surface was not covered with a waterproofing layer or painted with protective paints but was left to weather naturally.

2.6 Architectural form

This was a, perhaps unusual, example of an architect working closely with an engineer to develop a primarily structural form but also an architecturally elegant solution first proposed by the engineer. It shows how close interaction between architect and engineer from an early stage in a project may lead to a highly successful conclusion, as the completed building testifies. In this case, to a great extent the structure **is** the architectural form. It also demonstrates Isler's innovative use of a more conventional shell form – the hyperbolic paraboloid – by the adoption of a curvilinear plan and a manipulated orientation.

3. "STEINKIRCHE" CAZIS (1996)

3.1 Design concept

Heinz Isler's involvement in the development of the design for the "Steinkirche" of the Evangelische Kirchgemeinde in Cazis, Switzerland, [4, pp. 135-138] could not be more different from that of the church at Lommiswil. In 1994, the evangelical congregation of Cazis invited proposals from seven architects for a new church, a competition eventually won by Werner Schmidt from Trun [6]. His concept consisted of three linked ovoid forms, Figure 12.

Figure 12: *Evangelische Kirchgemeinde Steinkirche, Cazis. (Courtesy: Arch. Werner Schmidt)*

3.2 Design development

Heinz Isler was consulted as an expert in shell design and construction. For Isler, who by this time was nearing the end of his active design career, this must have been a strange commission. Unusually for him he was not asked to find the form of the shells but was given it, pre-determined by the architect. On a previous occasion, at the behest of architect Roger Taillibert, in Chamonix he had realised a collection of 28 rather flat triangular shells derived from the strict geometry of a spherical surface [4, pp. 86-89]. But in this case the architectural concept was of rounded stones in a stream - completely free-form shapes created by natural forces - which was represented in the model by three large potatoes. Werner Schmidt says that Isler was initially wary of the lack of structural optimisation of the forms but with time came to accept and appreciate them. This relates to Isler's belief in the power of nature to create efficient structural surfaces – in this case through growth, as applied in his shells based on observation of expansion of foam.

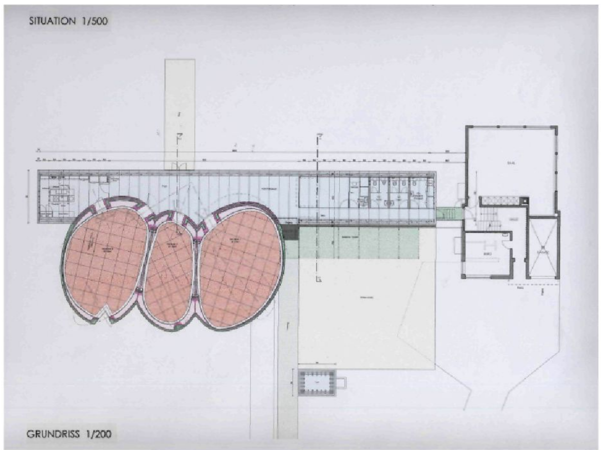

Figure 13: *Site plan of the Steinkirche, Cazis. (Courtesy: Arch. Werner Schmidt)*

However, the pebble shapes as adapted by the architect did not form continuous concrete shell surfaces due to the presence of several large lenticular incisions. These had been carved out of the potatoes, with a knife, by the architect, to create deep slot openings to accommodate glazing. As can be seen from Figure 12, they had no regular shape, orientation or position in the three linked shells. To understand the structural behaviour of the interconnected pebble forms, shown in the site plan (Figure 13) and partial section (Figure 14), and, in particular, the effect of these glazed openings, Isler returned to his tried and tested methods using physical models.

As Isler described in conversation with the author, in his studio in Lyssachschachen, in the summer of

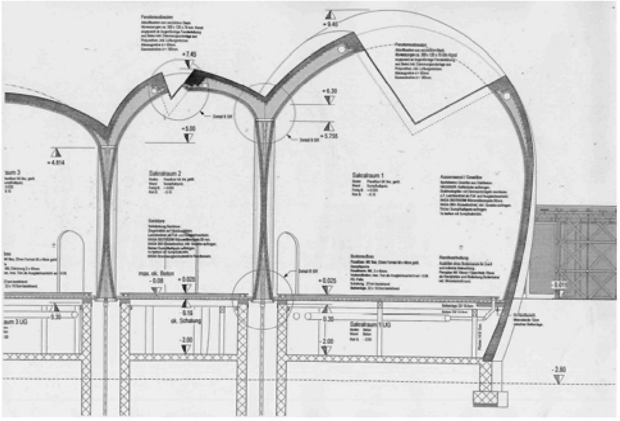

Figure 14: *Partial section through the Steinkirche, Cazis. (Courtesy: Arch. Werner Schmidt)*

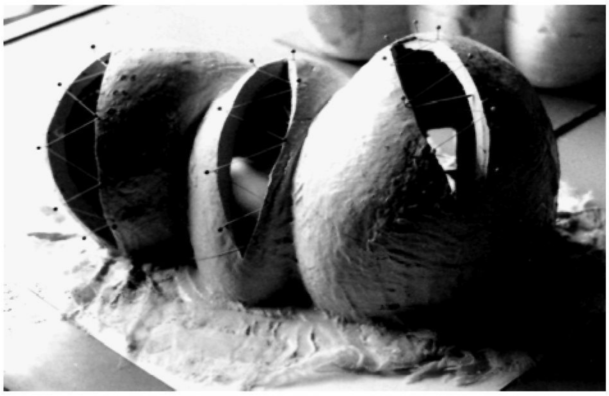

Figure 15: *Latex rubber model with diagonal lacing used to clarify force distribution across the lenticular openings. (Photograph: © Heinz Isler)*

1999, if the openings had been relatively small and more appropriately positioned, an approximation of the buckling behaviour of the shells could have been found by applying a slight negative internal pressure to a full flexible rubber mould of the forms [4, p. 137]. However, in this case the openings were neither small nor well located for optimum structural performance.

3.3 Lenticular openings

To transfer forces across the openings in the shells, the sides of the cut were to be linked by steel bars, whilst the glazing was installed in the plane of the cut surfaces of the removed wedges. In order to clarify the forces in the bars Isler made plaster casts and Styrofoam models of the forms, together with the architect. From these he cast thin latex rubber shells complete with the cut-out openings and with flexible cords linking the two sides, Figure 15.

These rods were disposed in a diagonal "zig-zag" configuration similar to that of the lacing on a traditional leather football or shoelaces, as seen in Figure 10. When the rubber surface was loaded it was easy to see how the flexible cords behaved. From his observations Isler concluded that the rods would mainly be subject to compression near the top of the ovoid forms and in tension towards the base.

In the final scheme the forces are carried by high-tensile Macalloy bars, some of which are left exposed whilst others, those carrying high compression forces are enclosed in steel tubes. To enable the same anchorage detail to be used in all locations, Isler developed a "brush anchor" with several smaller reinforcing bars that could be bent on site to mesh with the main reinforcement. Due to the diagonal pattern of the bars they are necessarily at different levels in the shell section to avoid conflict between the anchorages. This required a thickening of the shell edge around the openings.

Figure 16: *Styrofoam model used to determine building form and dimensions, clearly showing 1.0m contour levels. (Photograph: John Chilton)*

3.4 Measuring the form

Heinz Isler's normal method for determining the shape of his shells was to accurately measure a plaster cast of the form. In this case he used similar techniques. Styrofoam models at 1:20 scale were cut in horizontal slices to give contours at regular vertical intervals – as seen in Figures 16 and 17.

These contours were then used to produce vertical profiles at regular horizontal angles around a vertical axis through each form, centred at the highest point. The variability of the surface

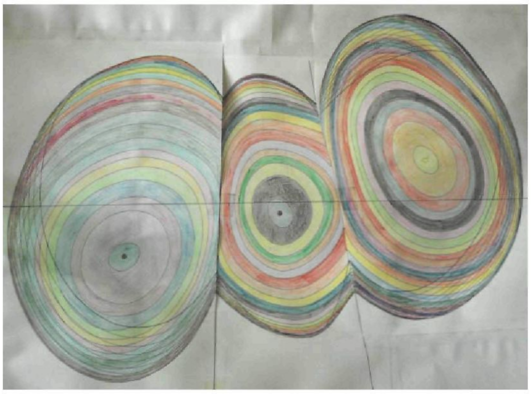

Figure 17: *Contour plot of the Steinkirche shells, still on the design office wall at Lyssachschachen in June 2011. (Photograph: John Chilton)*

curvature can be seen in the partial section through the building shown in Figure 14.

3.5 Construction

Unlike the Lommiswil Church where the roof slab – a segment of hyperbolic paraboloid surface - could be formed using straight board shuttering, the Steinkirche required the forming of three distinct but interlinked unsymmetrical, double-curved, convex surfaces. In one shell this required the forming of a large undercut – see the left-hand shell in Figure 12. Isler and his contractor Bösiger had considerable experience of creating double-curved surfaces using curved glulam timber beams but these were generally of relatively large curvature and, when compared to the stone pebble forms, relatively flat.

Heinz Isler had experience with inflated formwork for small scale shells, having experimented with the architect J. Dahinden, from Zürich, on the development of this form of construction for earthquake resistant housing destined to be used in Persia (now Iran). When that project was terminated before completion, he continued development of the system with his contractor Willi Bösiger AG for shells up to about 7m diameter. This system was successfully used, for example, for studio workshops in Ponthierry, near Paris [4, pp. 128-130] and a motel in Saudi Arabia, but was not applied here.

In the case of the Steinkirche, due to the lack of symmetry, larger size and complexity of the shells, this method was not considered appropriate. The solution adopted was to erect a system of radial

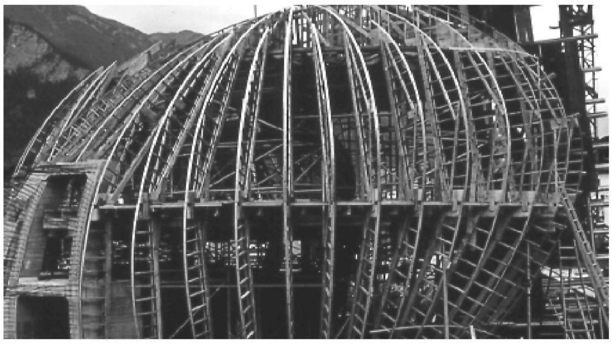

Figure 18: *Timber framing ribs used to support metal formwork before fixing reinforcement and spraying with concrete in approximately 30-40mm layers to a total thickness of approximately 150mm.(Courtesy: Arch. Werner Schmidt)*

timber ribs (108 in total), each made to the scaled-up profile determined from precise measurement of the model, and breaking the ovoid forms into an assembly of segments like those of an orange. These were supported at the perimeter of the ground slab, at approximately mid-height, and met at the top of the roof, Figure 18.

Figure 19: *Timber framing and ribs showing the intersection of the three ovoid forms. (Courtesy: Arch. Werner Schmidt)*

Thin perforated metal sheets were then fixed over the ribs to create the doubly-curved shuttered surface, followed by a separating membrane. Once the steel reinforcement was fixed the shells received roughly 150mm of sprayed concrete. This was applied in layers of approximately 30 to 40mm, as the timber falsework was not strong enough to receive the weight of the full shell thickness of wet concrete. Subsequent layers were, therefore, supported by the partially cured previous layers. Heavier supporting ribs were required at the inter-

Figure 20: *Timber box-out framing of one of the lenticular openings. (Courtesy: Arch. Werner Schmidt)*

section of the individual ovoid shells (Figure 19) and substantial box-outs to form the lenticular openings (Figure 20).

3.6 Finished shells

The external surface of the shells has a slightly undulating and textured surface resulting from the concrete spraying, which was left untreated. In a recent conversation with the author, the architect Werner Schmidt said that both he and Heinz Isler fully intended that the forms would mature over time, acquiring a patina of mosses and lichens, so that they would come to resemble the pebbles in the stream from which they were originally conceived.

Figure 21: *Exterior of the Steinkirche in May 2011, showing differential weathering patterns. (Courtesy: Ekkehard Ramm)*

Images of the exterior taken at the end of May 2011 (Figure 21) show a fairly uniform patina over the top half of each shell, whilst on the lower half of each the weathering is less uniform with evidence that rainwater flows in rivulets down the concrete surface, creating a streaked appearance. In contrast, the internal surface subsequently received a layer of thermal insulation and was finished with 20mm of plaster. This covered the shuttering marks and joints between different lifts of the sprayed concrete that can be seen in Figures 22. It also concealed the edge thickening for the bar anchorages around the window openings.

Figure 22: *Interior view of the sprayed concrete shell following removal of shuttering and before internal finish was applied. (Courtesy: Arch. Werner Schmidt)*

From the architectural point of view, as can be seen in Figure 23, the three linked volumes create a warm and protective cave-like space, illuminated by the sun streaming through the glazed notches cut in the shells. It is apparent that the interplay of shadow from the glazing bars and reinforcing bars

Figure 23: *Interior view of the sprayed concrete shell following removal of shuttering and before internal finish was applied. (Courtesy: Arch. Werner Schmidt)*

across the window openings, and the free-formed curved surfaces of the shells produce delightful patterns to stimulate quiet contemplation throughout the day. Figure 12 shows the welcoming glow which emanates from the shells when the interior is illuminated at night.

4. SIGNIFICANCE IN RELATION TO ISLER'S OTHER WORK

While the Steinkirche project and collaboration with the architect Werner Schmidt occurred relatively late in Heinz Isler's career it is significant in a number of ways, namely:

- The forms were given from nature in the guise of three large potatoes (representing pebbles in a stream) – via and modified by the architect.
- The forms were not of optimal shape in structural engineering efficiency terms – counter to Isler's normal practice – yet he came to accept them.
- They fulfilled one of the 39 etc. shapes Heinz Isler suggested in Picture 9 of his inspirational paper "New shapes for shells" [1] – at least one of the Cazis shells is very similar to the ninth form in the second column of that diagram, which is reproduced here as Figure 24, with the relevant form shown ringed in red.

5. CONCLUSIONS

Although Heinz Isler is best known for his "bubble" and expansion form shells and the "free-form" shells derived from the inversion of hanging membranes, this paper has demonstrated that in the two church structures with which he was associated he applied neither of these methods. In the first case, the Holy Spirit Church at Lommiswil, he used the more conventional form of a hyperbolic paraboloid, but in an innovative way. In the second case he was presented with a form by the architect and had the more conventional engineer's role of ensuring that the three spheroidal shells could be constructed economically.

6. ACKNOWLEDGEMENTS

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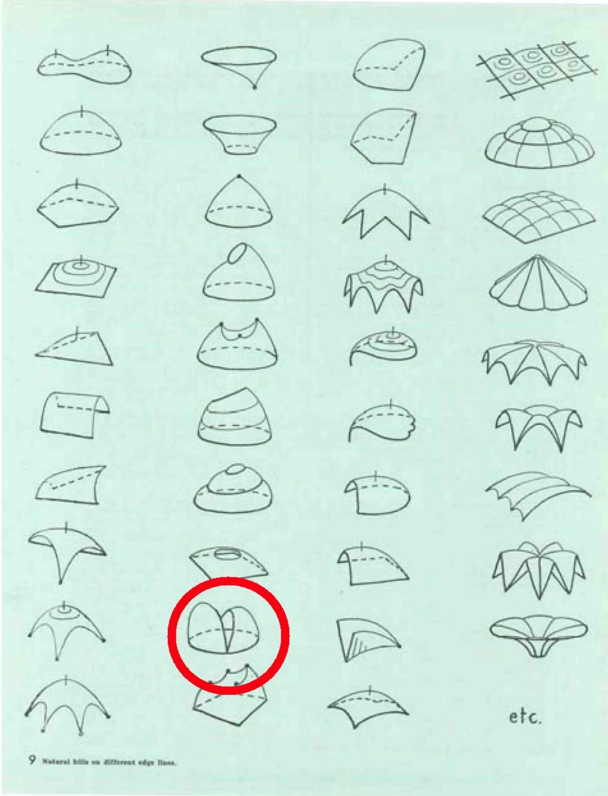

Figure 24: *Picture 9 from Heinz Isler's inspirational paper "New shapes for shells" [1], presented in 1959, showing prediction of Steinkirche-like shell form (ringed).*

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Finally, the author would like to declare his warmest appreciation to Heinz Isler for the inspiration, encouragement and knowledge that he gave, and to both Heinz and his wife Maria for their kindness and generosity over many years.

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