

## **39 etc... : Heinz Isler's infinite spectrum of new shapes for shells**

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### **Abstract**

The first Congress of the International Association of Shell Structures (now IASS), held in Madrid in 1959, was the occasion when Heinz Isler's innovative methods for determining the shape and constructing reinforced concrete shells first became widely known. Although he had introduced his ideas at smaller conferences as early as 1955, his Madrid paper 'New Shapes for Shells' (Isler [1]) was presented in front of some of the most eminent shell designers of the day. This paper included a diagram showing 39 alternative shell forms with the abbreviation "etc." at the bottom right-hand corner indicating that Isler believed there were many more possibilities yet to be revealed. Contemporary accounts of the discussion describe how his presentation completely astounded the assembled audience, which included renowned engineers such as Torroja, Esquillan and Arup. On the 50th anniversary of his presentation the content of the original paper and subsequent debate are reviewed.

Isler's form-finding and analysis was unassisted by modern digital design aids yet he was able to create efficient and economical structures of great elegance. His design and construction methods will be described and some examples of his shells, both built and unbuilt will be presented.

The paper concludes with a brief discussion of the influence that Isler's unconventional design philosophy, methods and extremely graceful shells have had on the development of free-forms in architecture over the last 50 years and hopefully will continue to have into the future.

**Keywords:** Heinz Isler, reinforced concrete shells, form-finding.

### **1. Introduction**

For almost half a century the Swiss engineer, Heinz Isler, has been a prominent participant in the symposia of IASS. However, perhaps his most significant appearance was at the first Congress of the International Association of Shell Structures (now IASS), held in Madrid from the 16<sup>th</sup> to 20<sup>th</sup> September 1959. This was the occasion when Heinz Isler's innovative methods for determining the shape of reinforced concrete shells first became widely known

through his presentation of a paper entitled ‘New Shapes for Shells’ (Isler [1]). At that time reinforced concrete shells were a very popular form of construction worldwide. However, their forms were almost entirely those which could be described easily by geometrical and mathematical formulae e.g. barrel vaults, spherical domes, conoids, and constructed using relatively simple formwork as in the case of the straight boards used for hyperbolic-paraboloid surfaces.

## **2. Paper C3 ‘New Shapes for Shells’**

Given the impact that this paper made it is surprising to learn how short it was. The first page has the Summary in English repeated as a *Résumé* in French, three photographs and their captions – in total about 200 words. The second is completely text and forms the core of the paper, which amounts to around 500 words, while the third has three photographs with captions. The next page has two photographs and fewer than 100 words while the fifth is a drawing with caption. The final page is also just under 100 words, giving a total length of approximately 900 words. In fact, this is more like an extended abstract! These comments are not intended to detract from the content of the paper but to reveal that one so short can convey so much.

To describe the contents in more detail, the pictures (as Isler referred to them) 1, 2 and 3 which accompany the Summary on the first page, show respectively a rounded mound of soil encircled by a trench and captioned “Form for a shell in concrete”; a stepped swimming pool of organic shape dug into the ground, labelled “Plastic shell as swimming pool”; and some rectangular ‘bubble’ shell roofs (two complete and two under construction), entitled “Rectangular shells 20 x 14m”, see Figure 1. These illustrate the two of the three form-finding methods described in subsequent pages.

### **2.1. Form-finding methods**

On the second page of the paper Isler states that “Among others there are three methods for shaping shells: the freely shaped hill, the membrane under pressure and the hanging cloth reversed.” Each method is then described in a little more detail with reference to the illustrations.

#### *2.1.1. Freely-shaped hill*

The mound is described as the mould for an unreinforced concrete shelter, tested to 60 t/m<sup>2</sup> and designed to resist the blast caused by the explosion of an atomic bomb. Effectively the pool of reinforced plastic only a few millimetres thick, is a negative mound, formed by excavation. Although Isler describes the method of shaping soil or sand as “prehistoric” and “primitive” he suggests that it gives the designer great freedom, to work “...with space, as a craftsman works with clay or wood.” However, he also urged caution in its application, as forms derived in this manner rely heavily on the experience of the designer and may not be statically efficient.

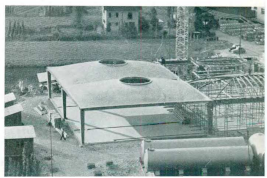
**C-3**  
**new shapes for shells**  
 HENZ ISLER, dipl.-Ing.

**SUMMARY**  
 Three methods are described which lead to new shapes for shells:

1. The freely shaped hill, which allows the structural engineer freedom, yet not every form.
2. The membrane under pressure, where plastic sheets are used for the form of concrete.
3. The hanging cloth reversed, where the form is made of wood.

**KEYWORDS**  
 Thin membrane, steel structure, and prestressed concrete, membrane structure, shell structures.

1. Form for a shell in nature.
2. Plastic shell as retaining wall.
3. Reversible shell (model).



Among others there are three methods for shaping shells: the freely shaped hill, the membrane under pressure and the hanging cloth reversed. Each of these three methods leads to a great variety of possible forms.

**1 the freely shaped hill**

The method of freely shaping a hill over any edge curve offers the greatest freedom for design. But it needs a good sense of statics and experience, by distinguish, the statically better form from the worse one. In case of doubt models may help.

Shells can even be poured on a hill shaped of earth, sand or other material. After the concrete has hardened we can either lift the shell or excavate the hill. For small objects this is a very cheap and simple method.

Picture 1 shows the hill of earth on which an atomic shelter was built of unreinforced concrete. The shell was still intact after a pressure test with 40 t/m<sup>2</sup>, which revealed thereby its enormous power of resistance. The photo is destined for military use (1954).

Picture 2 shows a swimming-pool built of reinforced plastic, designed as an inverse shell structure and built in the freely shaped mould of earth (1954). The thickness of the shell is only a few millimeters.

This 'prehistoric' method, however primitive, can in certain cases lead to very cheap solutions. It is the direct method where the designer works with space, as a craftsman works with clay or wood.

**2 the membrane under pressure**

The soap skin under unilateral pressure is a very useful method of getting new shapes. To every edge curve belongs a clearly defined form. Because all forms obey mathematical spatial functions, they possess the beauty of naturally grown shape.

Statistically these shells are reasonably good. If the dimensions are not too large, the error can be neglected arising from the fact that weights are parallel whereas gas pressure is perpendicular to the membrane.

Pictures 3 & 4 show shells of this type. The shape of the wooden scaffolding was checked by means of a rubber model. The prestressed shells are very light and economical. Since 1954 we covered over 11,000 m<sup>2</sup> of surface with these shells. The holes in the center are covered with translucent plastic shells of 5 m.

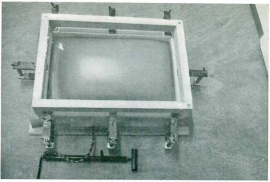
It is known that smaller shells of concrete as well as of plastic have directly been built on inflated balloons. If the bottom of the balloon is held in a steel frame (rectangle for instance) by this method we get also other forms than spheres.

**3 the hanging cloth reversed**

The hanging cloth is the best method for design. Hanging rods are well-known. But it may not be generally known that by reversal of certain hanging forms one gets excellent shells.

The hanging cloth is for three-dimensional problems what the catenary line is for two-dimensional arches. They obey the same fundamental principle. The hanging force being always parallel, we get automatically a system which safely can carry the loads. For large shells this method is the best.

4 Rubber model for shaping.



5 Reverse shells 30 x 30 m.



6 Acoustical shell (model).

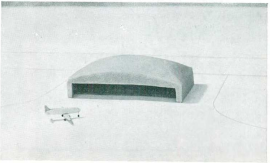


Figure 1: Pages 1 to 3 of 'New Shapes for Shells' (Isler [1]) Source: IASS Archive

### *2.1.2. Membrane under pressure*

Here Isler appreciates the value of soap films under pressure as a means of obtaining new forms "...they possess the beauty of naturally grown shape." and says that "Statically these shells are reasonable good." However, he qualifies this by recognising that where dimensions become large inconsistencies arise due to the gas pressure forming the shape acting perpendicular to the surface whilst self-weight acts parallel under gravity. Pictures 4, 5 and 6 on the third page (see right page of Figure 1) illustrate this method with a "Rubber model for shaping", "Square shells 20 x 20 m" (again 'bubble' shells) and an "Asymmetric shell (model)" for an aircraft hangar roof.

### *2.1.3. Hanging cloth reversed*

Because in the case of a hanging cloth the forces moulding the surface are gravitational, the reversed form is suggested here to be the best method for design of large shells, with a comment that this is "...for three-dimensional problems what the catenary line is for two-dimensional arches." The potential of this method is illustrated by picture 8, a 3 metre span ice shell made from a frozen cloth less than 1 mm thick and picture 7, which shows a reinforced plastic shell made directly by rigidizing the hanging cloth. Isler suggests that this method allows models to be made quickly and easily before testing for buckling stability to determine the most appropriate form.

## **2.2. Natural hills on different edge lines**

The spectrum of possible shells proposed by Isler in 1959 is shown in picture 9 of his paper, which bears the caption 'Natural hills on different edge lines'. The figure, reproduced here as Figure 2, displays 39 different 'hill' forms and is recognisably hand drawn by Isler himself. The final position at the bottom right corner of the four column by ten row grid is reserved for the abbreviation 'etc', which alludes to the infinity of potential shapes. Isler comments on this drawing in one short paragraph, the final one of his paper, reproduced in full here:

*"The drawings of picture 9 give a hint as to the tremendous variety of possible shell forms. To each edge line or system of lines and points there belongs a natural hill. This hill can be found by modelling, by pressure membrane, or best by hanging cloth. Many of the shell structures built up to now are included in the scheme." (Isler [1])*

Reviewing the variety of the 39 forms, one can recognize many that Isler constructed over the last 50 years. However, there are several that he appeared never to have built and one is inclined to ask "Why not?"

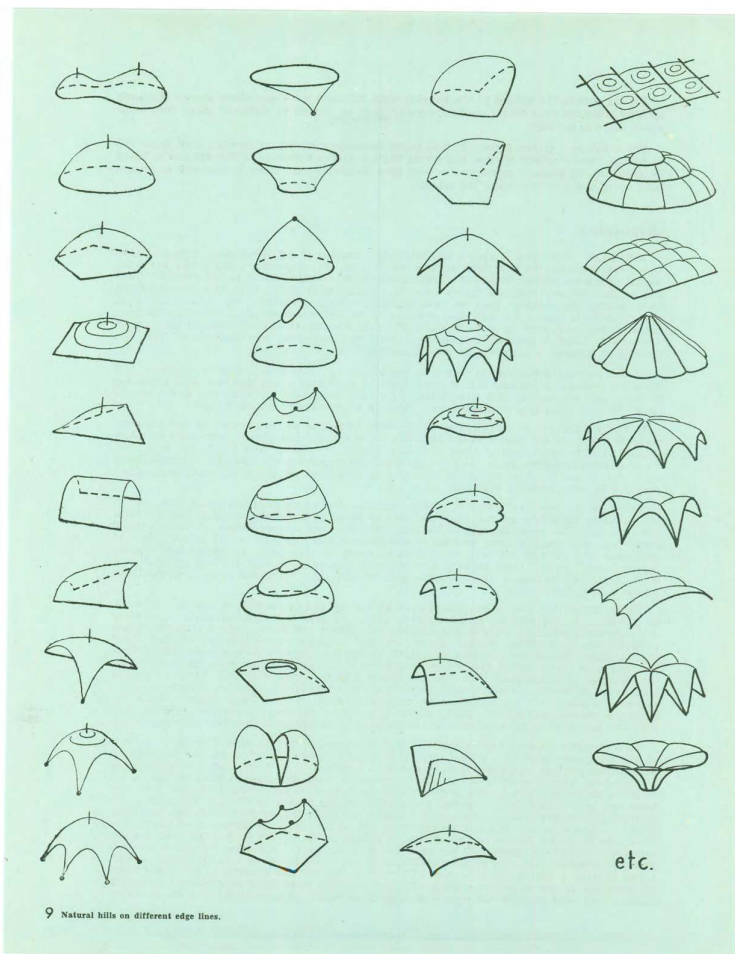


Figure 2: Picture 9 from 'New Shapes for Shells' (Isler [1]) Source: IASS Archive

### 2.3. Discussion – part 1

The impact of Heinz Isler's paper is confirmed by the debate which followed. Compared to the brevity of the paper the discussion (the majority in English but with parts in French) was extensive, running to almost five pages of dense text in the version printed in the IASS Bulletin. However, it may be inferred that this report of the debate is not complete. This is suggested by Heinz Isler's reported opening remark in the transcript of the discussion "After Prof. Torroja's very interesting analysis of my contribution I would like to add a few remarks." Such a comment implies that Torroja had spoken at some length before Isler responded. If this is the case, then perhaps this refers to the comments by Torroja in the General Report on the Fourth Session of the conference, although he may have made

further comment at the end of Isler's presentation. The General Report, which in itself runs to four closely typed pages, draws together arguments from the three presentations, by Hahn (describing the construction of the entrance canopy, designed by Nervi, for the UNESCO building), by Bennett (on doubly curved shells with straight line generators) and that by Isler. From the chairman, Parme's, remarks, it is clear that Torroja's report was delivered during the session.

In response to Torroja, Isler first remarks that he has been working with shell forms based on a soap film. He then lists the problems encountered in the design of shells, namely:

- the functional
- the shaping
- the architectural or artistic expression
- the statics
- the others – acoustics, light and so on.

Stressing the importance of the shaping, he says that this is "...a three-dimensional problem of a three-dimensional form...". He then draws attention to his understanding of the limitations of technical education, suggesting that at the time (and this is perhaps true even today) is inclined to emphasise "... straight lines and right angles ... symmetry in revolution ...". Further, he adds that for the three-dimensional forming of shells one needs to look for "...methods that are not limited to the designing [drawing] board, which is only flat..." but to consider "...freely modelling, just as an artist creates his forms; or...physical analogies... the membrane, the soap skin." The key point he is trying to make is that three-dimensional problems can be solved best by physical analogies.

Turning to the problem of statics, Isler points out that in a soap film forces are uniform, in equilibrium and without shear. A reinforced concrete shell, on the other hand, will accommodate shear and unequal stresses and usually has low compressive stresses. This gives a reserve capacity of strength. He finally remarks that "... if the boundary conditions are not quite accurate, the shape found, can easily carry the loads. I hope I make myself clear."

Torroja then replied at length (reported in French) indicating, initially, that he was in agreement, at least in general. However he had some reservations. He could see that physical analogies - membrane and soap film - were useful in representing and understanding shell form but he was concerned that intuition might replace experience. He raised the question of orientation of the yarns in a cloth model, commenting that a different form would result if the cloth were to be rotated by 45 degrees, because it is not an isotropic system. He raised the question of scale effects when transferring from model to full size structure. He contested the view that only straight lines and right angles were learnt at school (suggesting that things more complicated and general were also studied) but argued that one had to work with plans and mathematical definitions of surfaces. It was easy to imagine cylindrical and polyhedral forms, which could be made from paper, but for those of double curvature he knew only of clay, with which it is not easy to work. Further he remarked about artistic/architectural expression. With classical detailing of buildings numerous lines and details model elevations so that the architect is always aware of what they have designed but with double curved surfaces the form is only truly revealed by

shadows on the surface. It is, therefore, almost impossible for the designer to appreciate what they have created.

Before Isler could answer these points Esquillan, engineer for the lately constructed 200 metre span CNIT shell in Paris, raised more practical questions, those of construction method and cost. Esquillan, presumably drawing on his recent experience, suggested that these were problem enough with geometrical shell forms but that they would be exaggerated with free forms.

#### **2.4. Discussion – part 2**

Following a short refreshment break the discussion continued with a comment from Henderson about the danger of using a soap film as an analogy for the shape of a shell. He remarked that it was unlike a rubber membrane and "... not an engineering material, even remotely." He was followed by Ferry Borges, who appeared to support Isler's views, saying that rubber membranes made from strips of different thickness, to which inverse forces were applied, was the accepted method in his research institute for shaping models for three-dimensional stress analysis in dams. Scorer (an architect from Lincoln in the UK) then took the concept to an extreme by suggesting that there was an implication that sculptures by Henry Moore might be scaled up by 50 times as shells. However his question was more practical, concerning the thickness of the 20 metre square shell shown in picture 5 and the presence, if any, of ties.

In response, Isler gave the thickness, 80 mm in general with edge beams of 650 mm depth, and drew the approximate form of the diagonal section on a blackboard, while stressing the three important considerations for the free shape: equilibrium at the supports; boundary conditions at the edges; buckling stability of the shell. He emphasized the need to ensure that axes of forces from the shell diagonal, the column and edge beam pre-stressing intersect at one point, thereby confirming that ties were used.

He then moved to the issue of cost raised earlier by Esquillan, indicating that, with experience of constructing over 13000m<sup>2</sup>, this was slightly more than double that of shuttering a flat slab and represented approximately 20% of the overall cost of a shell.

Arup, founder of what is now one of the best known multidisciplinary design practices in the world, then spoke in support of Torroja's proposal of having joint conferences of engineers and architects, a principle which is maintained by IASS to this day. He then moved to the collaboration of engineer and architect in the design process, in the search for an economical, architecturally elegant and aesthetically pleasing building form, an issue which is very pertinent to Heinz Isler's form-finding techniques. Arup noted that, in practice, new shell forms are often used for 'spectacular' buildings (e.g. churches) where the architect initially decides the form. This Arup thought might be disastrous if the architect has little knowledge of shells, as they might propose a functional form that is, nevertheless, impractical and expensive to build. Collaboration with the engineer he hoped would avoid this, as the engineer would direct the architect to more economical and practical forms. In return he expected the engineer to become more aware of aesthetic considerations.

After this 'interlude' the debate returned to hard economics with Esquillan querying the 20% figure mentioned by Isler for the shuttering, by asking whether prices were very different in Switzerland. Using his experience of prices in France he calculated that around 50% of the cost of a shell resulted from the shuttering. The Chairman confirmed with Esquillan that this was for multiple uses and Isler also stated that this was true for his system. However, he went on to describe his shuttering technique, which uses thermal rectangular insulation boards placed on timber laths, draped over glue-laminated beams, and supported on lightweight trestles. As the insulation remains in place, less timber is used and is more easily reused, as it does not come in contact with the concrete. Isler said that this represented a maximum of 25% of the shell's overall cost, with the insulation contributing 7%.

Hajnal-Konyi then asked Isler about the geometry of the [bubble] shell, to which Isler responded that it was somewhere between a circle and an ellipse. He added that the form derived from the rubber model had been used to make a resin model which was tested under simulated load but counselled caution due to the different properties of the elastic material of this model and concrete. Torroja returned to the debate reporting that the form of rectangular shells on four corner supports had been previously studied concluding that the shell was spherical at the centre and conical near the supports. He considered that the construction system would have a strong influence on the structure and shape but not on the refinement of the shape. Therefore, the shape could be slightly modified without cost penalty in the shuttering. It is not absolutely clear here whether Torroja was proposing the refinement of Isler's shell shape or that of the theoretical model, although he does say that "... this small difference of shape can have a very strong influence on the amount of material used for building."

Isler countered "...it is a question coming to the very heart of the subject we are discussing now, the influence of the shape." He indicated that from his research the sphere was adequate for applied stress but lacked buckling stability when compared to the form determined from the rubber model. In addition, having experimented with conical forms at the corners, he had found that the "... shell model (being developable) was not stable and collapsed under very low load."

Tottenham asked whether Isler had compared the shape of the membrane with that of a soap film but Isler said that he had no means of measuring the soap film. This was followed by a question from Hajnal-Konyi concerning exactly how the co-ordinates were measured sufficiently accurately to be scaled up significantly. Isler answer somewhat obscures his technique using a simple measuring rig, as shown in Figure 3, but describes the mathematical smoothing of the measured form once plotted at large scale. In interviews with the author, Isler has said that only he measured the models, to ensure consistency of technique, sometimes working late into the night alone in his studio.

Torroja here interjected that an electrical analogy was more appropriate than a soap film before Boehmer asked what effect shape modification had on the shell's resistance. Isler replied that a 7-10% improvement in buckling stability had been obtained when compared with a sphere but 100% local improvement when compared with the shell with conical sections.



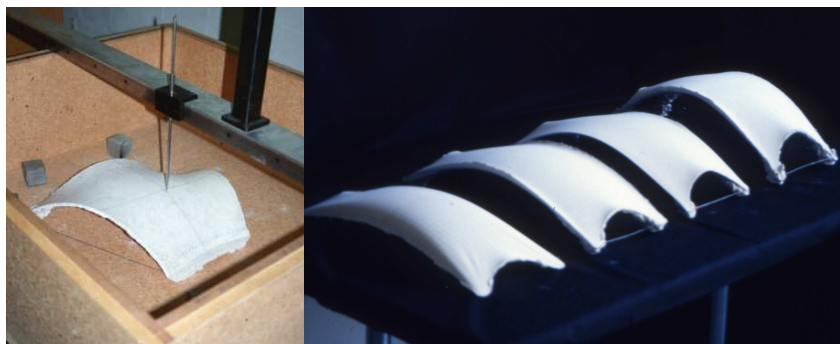


Figure 3: Isler's rig for measuring the 3D profile of cast shell models (left) and a series of exploratory models for tennis hall shells (right). Photographs: John Chilton

The final comments came from Flint, founding partner of Flint & Neill, London, who was concerned that architects would "...get the impression that they can just take a rubber membrane, fit it to a given boundary and blow it up, and the engineer will then construct the form." He was worried that shells being constructed had higher rise/span ratios which increased the discrepancy between behaviour of a membrane under pressure and a shell under gravity loads. In addition, he was worried about scale effects, suggesting that one would not expect to be able to scale up a snail's shell by 1000 times without problem, and also drew attention to the effect of lateral loads from wind etc.

Concluding the discussion Isler made it very clear that he understood the limitations of his modelling techniques but that he also saw their potential to shape innovative, exciting, efficient and aesthetically pleasing new shell forms. His final words were:

*"...I do not say any form which you construct this way is a good form, or must lead to a good solution; but there are forms which can lead to good solutions, and of course that is only the first link in a whole chain of investigations, and the other links in the investigation, model tests, measuring of the first structure, or a model test in scale 1:1 as we have it out here, these are of primary importance. So the engineer[ 's] problem is remaining all the same, but it is the first link, here, the shaping which has been lacking up to now, and this method can lead to a very nice solution. Thank you."*

### **3. 'New Shapes for Shells' – 20 Years After**

At the World Congress on Shell and Spatial Structures, the 20<sup>th</sup> anniversary of IASS, also held in Madrid, Heinz Isler presented a retrospective view (Isler [5]) of his work since his presentation of the original paper in 1959. To illustrate how his confidence and portfolio had increased, unlike the original rather brief paper, this time the contribution extended to 18 pages in the Bulletin of IASS with over 70 illustrations. It is interesting to look back now and assess Isler's own view of the effect of the paper he had presented twenty years earlier, as a relatively young engineer of just thirty-three years.

In this subsequent paper Isler comments on the discussion and the fact that Torroja “...pointed out repeatedly the consequences and problems involved in free shaping.” He revises his list of methods for shape finding. This time it includes analytical methods (membranes, flowing forms, hanging reversed membranes) and other methods (sculptured forms, simulation of shells in Nature, etc.) saying that any one of these can be used depending on the architectural constraints and the designer’s concept. (Isler [5])

On this occasion again the paper had little text but contained numerous examples of built projects categorised according to the shape finding method used. There were also a few unbuilt designs such as the proposal, based on the pneumatic form-finding technique, for a 150 m diameter warehouse roof with inner courtyard containing a tower with a revolving restaurant at its top. As Isler notes this would have provided 15,000m<sup>2</sup> of accommodation with no internal columns.

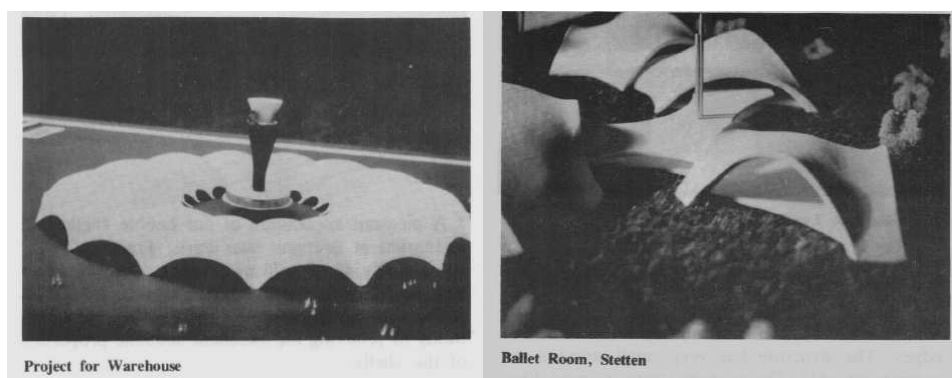


Figure 4: Images of shells built (right) and unbuilt (left) taken from ‘New Shapes for Shells’ – 20 Years After (Isler [5])

His review of twenty years of his own work concludes with five points which I quote here in full:

*“One might draw the following conclusions:*

- *formfinding is one of the most important factors in shell design. I would say it is the most important one.*
- *each of the mentioned methods leads to an unlimited number of forms*
- *the method of the hanging reversed membrane seems to be the most efficient one*
- *the deformation pattern – calculated or experienced on models or on site – might be a criterion of qualification of the shapes*
- *a high precision of form finding investigation is worthwhile for shells of medium span (30m) but is indispensable for shells of large span.”*

(Isler [5] p25/26)

The paper ends on a very positive and optimistic note suggesting that the future was bright for architectural reinforced concrete shells, "...seeds sown 20 years ago have born[e] fruit richly and can continue to do so in the future." However, this paper was given at what was probably the zenith of Isler's shells.

#### **4. Conclusion 'New Shapes for Shells' – 50 Years After**

Isler did not actually construct his first shells in the UK until 1987, at Norwich Sports Village, and the last was completed in 1991 [2]. This is indicative of the decline of reinforced concrete shells in buildings in Europe and North America. Fifty years after Heinz Isler's presentation of his paper 'New Shapes for Shells' the construction of such roofs has become relatively rare. Nevertheless, the diversity of shell forms that Isler proposed is still there to be explored, although today this would be more likely to be through the medium of digital modelling than with physical models.

It is interesting to note that one of projects completed near the end of Isler's career, the group of 'stones' for the Evangelical Church at Cazis, in Switzerland [1], somewhat resembles one of the 39 forms presented in the paper – second from left in the penultimate row, Figure 5.



Figure 5: Evangelical Church, Cazis, Switzerland (1996). Photograph: Heinz Isler

It is slightly ironic that this was one occasion when the shell forms were developed by the architect, rather than Isler, as their competition-winning model was composed of just three rounded stones, an example of Isler's use of forms suggested by Nature.

Although the construction of free-form reinforced concrete shells has declined dramatically, Isler's ideas about form-finding and the efficiency of such structural forms lives on in the current architectural fashion for three-dimensionally curved building envelopes.

## **Acknowledgement**

The author would like to thank the IASS Secretariat for supplying scanned images of both of Isler's papers discussed here and permission to use them as illustrations in the text.

## **References**

- [1] Chilton J., *An Engineer's Contribution to Contemporary Architecture - Heinz Isler*, Thomas Telford Ltd, 2000, pp135-138
- [2] Chilton, J.C., 1992. Shell comeback, *Concrete Quarterly*, Vol. 173 (Summer), pp. 24-26
- [3] Isler H., New Shapes for Shells, *Bulletin of the International Association for Shell Structures*, 1961; **8**: 123-130
- [4] Isler H., New shapes for shells – Twenty Years After, *Bulletin of the International Association for Shell Structures*, No 72-3, 1980, p9-26