8 Form-finding and fabric forming in the work of Heinz Isler

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In his remarkable paper “New Shapes for Shells”, presented at the first conference of the International Association for Shell and Spatial Structures, in Madrid, Heinz Isler (1926-2009) proposed three methods of form-finding – “…the freely shaped hill, the membrane under pressure and the hanging cloth reversed.” Of these he considered the hanging cloth reversed (i.e. fabric forming) to be the most satisfactory and this was the method he used to find the shape of his most iconic works such as the roofs of the N1 autobahn service station at Deitingen and the Sicli factory in Geneva. Although this technique (hanging and inversion) can be used directly to form small to medium scale objects, it is not feasible for the large shells constructed by Isler. However, it can be utilized for form-finding. This paper describes the process used by Isler to apply the principle of fabric forming to the creation of full scale shells and relates this to his experiments with fabric forming of ice structures, which suggested the, mostly unrealized, potential of the method.

1 Introduction

Numbering fewer than 900 words, Heinz Isler’s paper “New Shapes for Shells” (Isler,1961), presented at the first conference of the International Association for Shell and Spatial Structures, in Madrid, in September 1959, was brief but highly significant (Chilton, 2009; Billington, 2003). Speaking in front of more established shell builders such as Eduardo Torroja, Nicolas Esquillan and Ove Arup, he introduced three non-conventional form-finding methods for shells “…the freely shaped hill, the membrane under pressure and the hanging cloth reversed” (Isler, 1961:2) and showed examples of their use in some of his own projects.

Of these, he commented that he considered the hanging cloth reversed (i.e. fabric-forming) to be the most satisfactory. This was the method he subsequently used to find the shape of his most iconic works such as the roofs of the N1 autobahn service station at Deitingen Süd (1968) and the Sicli SA factory in Geneva (1969). Although this technique (hanging and inversion) can be used directly to form small to medium scale objects, it is not feasible for the long-span shells constructed by Isler. However, it can be utilized for their form-finding.

The paper concluded with a sketch, by Isler, shown in Figure 1, indicating 39 potential shell forms and an “etc.”, suggesting that there might be an infinite number yet to be discovered (Chilton, 2009).

2 Hanging cloth reversed

Isler has commented that he first realised the potential for form-finding with a hanging cloth when he noticed the shape of jute fabric (used wet to aid the curing of concrete) draped over steel reinforcing mesh (Chilton, 2000:35). Early experiments with the technique, using a wet sheet suspended from four poles on a freezing winter evening, are illustrated in his paper “New Shapes for Shells” (Isler 1961:4), with illustration 8 showing the frozen inverted ‘ice shell’, see Figure 10 below.

2.1 Basic technique

For form-finding of his shells Isler loaded the fabric surface with a plaster of his own formula developed to maximize mouldability when wet whilst maintaining a constant thickness on the curved fabric and minimizing cracking of the drying surface. However, Isler also realized the shortcomings of this technique, due to the influence of fabric weave and its orientation relative to the boundaries.

Figure 1: Illustration 9 from Isler's paper "New Shapes for Shells" (Isler,1961:5), courtesy IASS.

To minimize these effects, for more accurate modelling of the hanging surface, Isler employed a selected high-quality latex rubber membrane which has consistent isotropic properties. Figure 2 shows the application of this technique for a form-finding model for the Sicli SA factory shell in Geneva.

Figure 2: Latex rubber form-finding model for the Sicli SA factory shell in Geneva (Photograph: John Chilton)

That there are almost no surviving examples of this technique is explained by the fact that in order to accurately measure the formed surface the latex rubber former has to be removed.

It is interesting to note that Isler also seems to have experimented with a mechanical method of form-finding. This was observed in June 2011, when the author visited Isler's studio in Lyssachschachen, near Burgdorf (shortly before the contents were moved to the Eidgenössische Technische Hochschule (Swiss Federal Institute of Technology), Zürich (ETHZ)). The assembly consisted of a wooden frame from which was suspended a triangular piece of latex rubber, similar in form to Isler's Deitingen Süd motorway service station shells. An approximation to a uniform load was applied to this surface through small timber discs distributed across it. The discs were connected via a system of strings and spreader bars culminating in a single string attached to a small pulley wheel and handle on the base below. On turning the handle the strings pulled down on the discs thereby imposing a load on the latex and deforming it into a double-curved surface, see Figure 3. Unlike Isler's standard form-finding method, where once the shape, size and suspension points of the surface had been fixed the load exerted by the wet plaster creates a unique profile, this rig generates different forms depending on the load applied. However, as no rigid surface is produced it would have been very difficult to measure. It is suggested, therefore, as only one example is known to exist, that Isler used this to demonstrate the principle and range of possible form generation rather than as an alternative design method.

2.2 Selection of form

As noted previously, for any given plan shape, the number of forms that can be found using a hanging membrane is potentially infinite. Hence, what are the factors that influenced Heinz Isler's selection of the preferred constructed form? A photograph taken of Isler during the presentation of his paper "New Shapes for Shells" in Madrid, in 1959 (Billington, 2011; Ramm, 2011), shows that he had written with chalk on a blackboard - no digital media being available at that time - what he considered the key factors to be, namely:

- Functional

- Shaping
- Artistic expression
- Statics
- Construction
- Cost

Of these he had emphasised 'shaping' and 'cost'.

Figure 3: Mechanical form-finding rig for surface similar to the Deitingen Süd motorway service station shells seen in Isler's studio at Lyssachschachen (Photograph: John Chilton)

Isler, as designer, determined the shape and size of the fabric surface he used in the form-finding. However, as with a simple catenary chain, the smaller the sag of the three-dimensional hanging fabric or membrane surface, the greater the magnitude of horizontal thrust to be resisted by the shell and at the supports. Conversely, the greater the sag, the lower the thrust but the greater will be the surface area of the roof and, consequently, the higher the self-weight and vertical load to be resisted at the supports. Therefore, the shape and size of the initial surface evidently influences the support reactions and the stresses within the shell.

A further consideration is buckling of the shell under compression stresses, particularly at the free edges and where loads concentrate near the supports. In more traditional geometrically determined shells, such as hyperbolic paraboloids, this frequently necessitates the incorporation of an edge beam. However, from his experiments with ice shells (see Section 5), Isler realized that by making his initial surface slightly larger than the plan area between the supports local modelling and double curvature of the thin shell edge could contribute the required stiffness to resist buckling. The overall size, shape and location of suspension points of the initial surface therefore influence the resulting surface.

This led Isler to make a series of hanging models for each shell project, for example see Figure 4, which shows models for the standard, typically 17.75 or 18.6 m wide x 48 m long, tennis hall shells, such as those constructed in Norwich, UK. The different profiles, some flatter, some steeper can clearly be seen.

From the series of models Isler was able to assess the appearance of each in terms of the aesthetics, approximate compression stresses within the surface and approximate buckling resistance.

In conversation with the author Isler said that he was able to calculate approximate self-weight stresses in his square and rectangular plan shells very easily – as he put it "while walking between my study and the tea room". From the shell area he knew the approximate vertical reaction at each corner and from the angle the surface made with the horizontal he could calculate the horizontal thrust and hence the resultant force in the support. Distributing this over the area of shell at the mid-span (shell thickness times curved length of section) gave him an average stress.

He was therefore able to assess each form qualitatively and to some extent quantitatively in a relatively short time. The selected form then proceeded to be precisely measured and the structural behaviour of the surface was accurately determined with load tests on resin models.

Figure 4: Series of form-finding models for Isler's standard typically 17.75 or 18.6 m wide x 48 m long tennis hall shells. (Photograph: John Chilton)

3 Determining the geometry

At the time Heinz Isler was using this form-finding technique modern methods of surface profile determination, such as laser-scanning, were not available to him. To obtain sufficient and appropriate x, y and z-coordinates to enable the full-scale shell to be constructed, the plaster surface, typically, at approximately 1:50 or 1:100 scale, had to be accurately measured. This was achieved manually using the selected plaster cast placed within a special measuring jig. As can be seen in Figure 5, this consisted of a timber box with scale rules embedded in the side frames to give x and y co-ordinates. The z-coordinate was found using a guided pointed probe suspended neutrally (with its weight balanced) from a dial gauge.

Before placing the plaster cast in the jig a network of grid lines was drawn on its surface. The grid density generally varied depending on the shape of the surface, degree of curvature and detail required. For instance, near the corner supports where the slope of the shell is steeper a greater density was usually employed.

Figure 6 shows the plaster cast for one of the group of free-form shells designed in collaboration with architect Michael Balz and built at Stetten auf den Fildern, near Stuttgart, prepared for measurement with the grid drawn on the surface.

To minimise inaccuracies, coordinates for each point on the model shell surface were measured a number of times and the mean value was taken. According to Isler, being the most critical stage in the process, this was carried out only by himself.

Figure 5: Isler's measurement jig (top, photograph: John Chilton); Form-finding model prepared for precise measurement in the special jig. (Bottom, photograph: John Chilton)

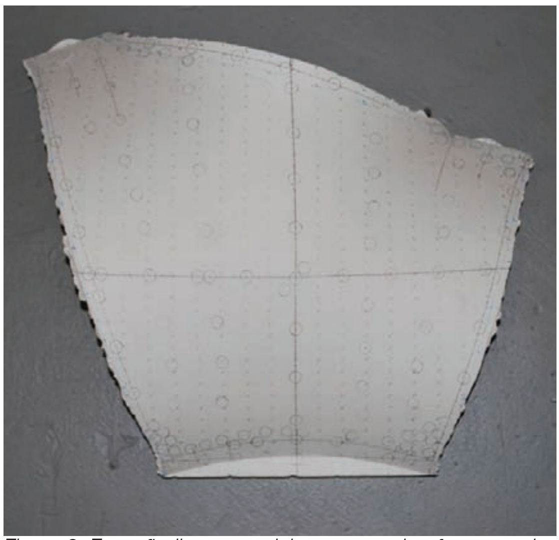

Figure 6: Form-finding model prepared for precise measurement in the special jig. (Photograph: John Chilton)

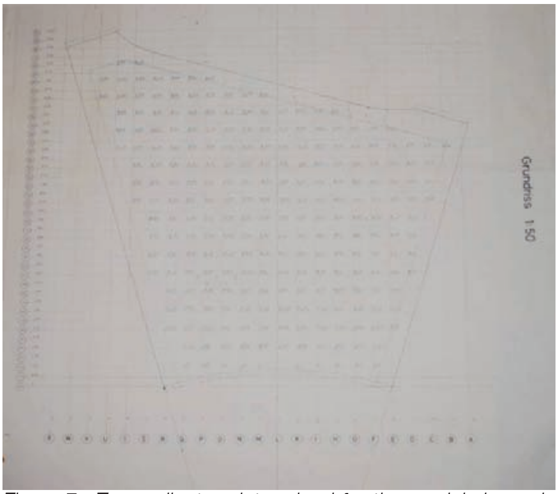

Figure 7: Z-coordinates determined for the model shown in Figure 6 marked on the 1:50 plan. (Photograph: John Chilton)

The z-coordinates determined for the model shown in Figure 6 are marked on the plan view shown in Figure 7. Profiles were then plotted at larger scale to check for inconsistencies and any perturbations were smoothed.

4 Proving the form

Heinz Isler was renowned for his distrust of computers and, certainly during the early part of his career, finite element programs capable of analysing his shells were not widely available. Hence, following in the steps of his mentor Lardy, he used physical models to prove the structural robustness and stability of his forms.

Epoxy resin models were made using the plaster models as forms and these were load tested in purpose made experimental rigs to determine internal forces and the shell buckling resistance. Works of art in their own right, the models and rigs were designed to replicate a variety of loading conditions, including for instance differential movement of the supports.

By their nature, each of Isler's free-form shells is unique and, therefore, requires a new model to be made and tested for each type. Examples of these are shown in Figures 8 and 9 for the Gips Union SA factory, Bex (the first of Isler's free-form shells to be constructed) and the Sicli SA factory Geneva, respectively.


Figure 8: Structural model for the Gips Union SA factory in Bex, Switzerland, 1968. (Photograph: John Chilton)

5 Ice shells

As he described in his paper presented at the International Association for Shell and Spatial Structures (IASS), Structural Morphology Group Colloquium, held at the University of Nottingham in 1997 (Isler, 1997), Heinz Isler experimented - one might even say played like a child – with thin structures of ice over many years. He commented "Your wildest imagination is modest compared with the richness nature can produce" and noted the ephemeral nature of his 'discoveries'.


Figure 9: Detail of structural model for the Sicli SA factory, Geneva, 1969. (Photograph: John Chilton)

Taking advantage of the cold Swiss winters and the extensive grounds around his house in Zuzwil he made a range of frozen shapes using just water and fabric. The early example from the paper he presented to the IASS Congress in 1959 is shown in Figure 10, where the stiffening effect of excess fabric at the edges can be clearly seen.

Figure 10: The hanging and inverted membrane shown in Isler's IASS Congress paper, 1959. (Photographs: © Heinz Isler Archive)

From the simplest sheet hanging from four corners used to create an arched grotto, Figures 11 and 12, to the free sweeping draped forms shown in Figure 13, all were initially in tension.

Figure 11: A simple hanging sheet when frozen forms an arched grotto. (Photo: ©Heinz Isler Archive)

The hanging ice shell in Figure 11 has not been directly inverted when used in the small grotto shown in Figure 12, hence the shells are not in pure compression, yet stand nevertheless. However, those of Figure 13, once the original support has been removed become compression forms.

Figure 12: When combined they create an arched grotto. (Photograph: © Heinz Isler Archive)

6 Discussion

Given the facility and creative potential of this form-finding method, as demonstrated by Heinz Isler's experiments with ice forms described above, it may appear surprising that a greater number and variety of free-form Isler shells were not built.

Putting aside the fact that the form of a building is usually determined by the architect and that Isler, as engineer, would have had the difficult task of persuading the architect to adopt a self-generated form, there is the fundamental difficulty of economically forming complex double-curved reinforced concrete shells. In Isler's case this was alleviated to a great extent by eliminating single use formwork, where possible, and utilising thin flexible timber laths draped across reusable curved glulam timber beams supported on lightweight temporary scaffolding. Although not truly a fabric, the thin laths nevertheless might be considered equivalent to its warp or weft threads.

Figure 13: Draped frozen fabric becomes self-supporting in compression once the supporting forms are removed (Photograph: © Heinz Isler Archive)

Figure 14: Draped frozen fabric initially supported by a central pole (Photograph: © Heinz Isler Archive)

The approximately 6m high tent-like ice structures of Figures 13 and 14 at first appear unlikely candidates as models for reinforced concrete shells. They were created by draping open weavThe approximately 6m high tent-like ice structures of Figures 14 and 15 at first appear unlikely candidates as models for reinforced concrete shells. They were created by draping open weave fabric (in tension) over a supporting pole before spraying water until the ice layer became approximately 10mm thick. Once frozen the central pole was removed allowing the ice shell to stand on the ground carrying its own weight in compression. The scale of the ice shell can be judged by comparison with Isler's wife Maria, who is seen bravely standing inside, see Figure 15.

Yet, a similar form has been designed and built by Japanese architect Shoei Yoh. Using a deployable woven bamboo gridshell – effectively an open weave bamboo fabric draped over temporary supports - he created the formwork support for the reinforced concrete roof of Naiju Community Center and Nursery School, Fukuoka, Japan, 1994 (Stungo, 1998; Yoh, undated).

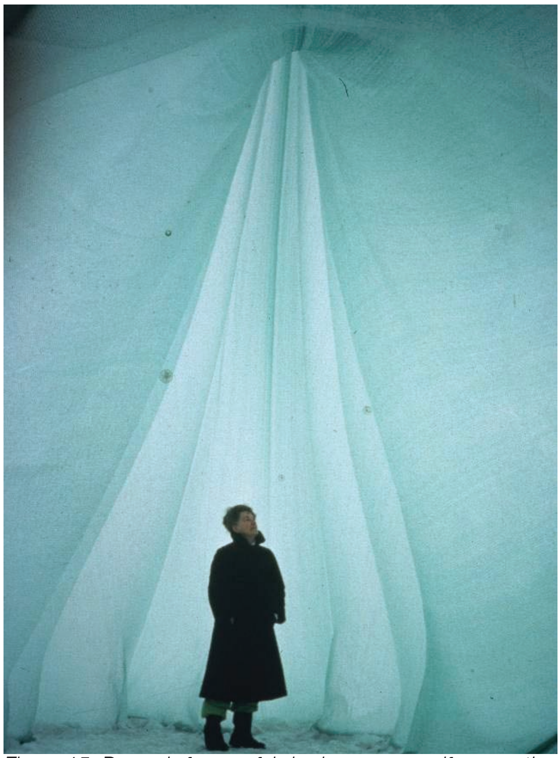

Figure 15: Draped frozen fabric becomes self-supporting in compression once the supporting pole is removed (Photograph: © Heinz Isler Archive)

7 Conclusions

Reinforced concrete shell structures directly formed with fabric are generally considered feasible at the small scale. However, due to handling difficulties the usual method of construction, involving inversion of material cast on a hanging form suspended under tension is generally not feasible at the scale of Isler's shells.

Nevertheless, as the free-form shells of Heinz Isler demonstrate, this does not signify that fabric forming cannot be used in the process of design and construction of large reinforced concrete shells.

In Isler's work fabric-forming is the fundamental stage in the design process, allowing him to quickly explore a multiplicity of forms and to develop efficient and elegant structures. During construction the formwork surface is directly supported on primary glulam timber beams on lightweight scaffolding, which support flexible timber laths that emulate an open weave fabric.

8 Acknowledgements

The author would like to thank the Heinz Isler Archive for granting permission for inclusion of copyright images.

9 References

Billington D. P., 2003. *The Art of Structural Design: A Swiss Legacy*, Princeton University Art Museum/ Yale University Press, pp130-131

Billington D.P., 2011. Heinz Isler: from Delft to Princeton and Beyond. *Journal of the International Association for Shell and Spatial Structures*, IASS, Madrid, Vol. 52 (3), No. 169 , pp135-141

Chilton J., 2000. *Heinz Isler: Engineer's Contribution to Contemporary Architecture*, Thomas Telford Ltd.

Chilton, J.C., 2009. 39 etc...: Heinz Isler's infinite spectrum of new shapes for shells. *In* Lázaro, ADC., ed. *Evolution and Trends in Design, Analysis and Construction of Shell and Spatial Structures*, Editorial de la UPV (Universidad Politécnica de Valencia), Valencia, Spain, pp51-62

Isler H., 1961. New Shapes for Shells. *Bulletin of the International Association for Shell Structures*, 8, c-3.

Isler H, 1997, Transparent structures of fibreglass and ice. *In* Chilton J.C., Choo B.S., Lewis W.J. and Popovic O eds., *Structural Morphology: Towards the New Millennium*, University of Nottingham, pp3-10.

Ramm E., 2011. Heinz Isler Shells – The Priority of Form. *Journal of the International Association for Shell and Spatial Structures*, IASS, Madrid, Vol. 52 (3), No. 169 , pp143-154

Stungo N.,1998. *The New Wood Architecture*, Laurence King Publishing, pp96-101.

Yoh S., undated. *Elastic Architecture*, available at http://www.jade.dti.ne.jp/shoeiyoh/Essay/ELASTIC%20ARCHITECTURE.pdf (Accessed 23 February 2012).