Deployable Gridshells and their application as a Physical Form Finding Tool: Constructing an innovative life-size Strained Timber Gridshell

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Deployable Gridshells and their application as a Physical Form Finding Tool: Constructing an innovative life-size Strained Timber Gridshell

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Summary

This paper presents and discusses the outcomes of a recent participatory workshop where timber gridshells were designed and constructed intuitively by architecture students using physical models. These timber gridshells, constructed from deployable timber lattice mats, are deformed to become structures observing double curving geometries. After weeks of public exhibition, they were taken down, collapsed and stored away for erection a few months later. The possibility of reusing this deployable mat to achieve different forms resonates with the quest for construction efficiency, ease and sustainability. This paper speculates and investigates this system of shell form-finding as a reusable form-finding tool, to induce understanding of shell action, from an architect's point of view, informing future designers of their structural logic, ease of construction and sustainability.

Keywords: concrete; thin shell; formwork; gridshell; reusable; formfinding

Fig 1 The completed gridshell entitled THE SWELL, Sheffield Hallam University 2011

1. Introduction - Strained Timber Gridshells

The construction of structures by deforming a flat grid mat has seen a come-back over the last decade. This method was first investigated seriously at the Institute of Lightweight Structures at Stuttgart University where under the direction of Professor Frei Otto where a number of experimental structures were built and investigated. The results are seen in the first engineered gridshell built for DEUBAU, the German Building Exhibition at Essen, Germany in 1962. The series of studies subsequently culminated in the publication of IL10 devoted to the gridshell.[1] This technique of construction by deforming a flat timber lattice mat into a 3-dimensional architectural piece was eventually applied on the construction of the roof of the Multihalle in Mannheim, Germany built for the National Flower Show between 1974-1975.[2] Otto used the term "gritterschale" (gridshell) to describe a grid of wooden slats that is curved twice over its extended area by the bending of the slats and angular twisting at the points of intersection. More recently, the strained timber gridshell [3] took centrestage in the Weald and Downland Jerwood Gridshell building in 2001 by Edward Cullinan Architects, London, followed by the Savills Gridshell by Glenn Howells Architects completed in 2005.

The design of strained timber gridshells requires a good understanding, amongst many things, of the craft (process/ sequence of construction) and material (structural behaviour). They are a family of structural system that is related to a specific process and method of construction- where fore-planning of the structure and the sequence of erection are integral and essential. They are architecturally intriguing structures with a material sensibility and shows off the material capabilities of timber, at the same time offering spectacular visual expressions of structural legibility – an ideal case of architectural tectonics. The variation of grid density variation affects the pliability of the flat mat and the stiffness of the resultant strained gridshell.

The design and construction of a timber gridshell was organised to inculcate in the architecture student a cognitive understanding of timber and the integral design process.

2. In the tradition of the Physical model - Structural Intuition [4] and Creative Play [5]

In his 1966 book, Aesthetics and Technology in Building (translated from the original Italian text , Nervi talked about "intuition" in design. [4] He also wrote about the use of the architectural modelling to work out the most aesthetically pleasing form for the project design. He believed that aesthetics came from the imagination of the architect, the designer and was not dictated by only by statics calculation and accuracy of calculation.

> *"How to develop in students a static sense, an indispensible basis of intuition of structural imagination, and how to give them a mastery of rapid, approximate calculations for purposes of orientation."* Nervi, 1966. [4]

The use of the physical model was also strongly advocated by the renowned form-finding methodologies held by the late Heinz Isler, who formally expressed this sentiment in his 1997 IASS paper entitled "Is the Physical Model Dead?" [5] Isler favoured the physical model as a way of appreciating, understanding and ultimately creating forms. In fact, he liked touching the models and occasionally found weak areas in the structure, for example low curvature prone to buckling.[6] The physical model was capable of demonstrating structural behaviour that statics and calculations was unable to.

This “Creative Play” [5] approach was the educational objective of this weeklong activities where design workshops were enhanced by real scale construction activity and speakers speaking on shell and innovative timber design and construction.

3. Timber Gridshell Workshop at Sheffield Hallam University, March 2011

The students of Sheffield Hallam University participated in a life-size workshop to learn about this type of structures by designing and constructing timber gridshells during a week of material explorations in timber. A flat site along across from Sheffield train station owned by Sheffield Hallam University was chosen for its visibility for the week-long construction workshop.

3.1 Scaled paper gridshell model and grid mat deformational behaviour

Prior to building the structure at full scale, the participating students explored the construction and form-finding by using 1:50 models from 5mm wide paste-card strips. These were firstly pin jointed together at their intersections to form a gridded mat. (fig. 2) The pin-joints replicated the swivel action that facilitates the deformation of the grid. With this ability to deform, i.e. as square grids become diamonds, the overall mat itself was able to lengthen and shorten along this flat plane. The material remains 2 dimensional, although the mat changes shape and area coverage on plan.

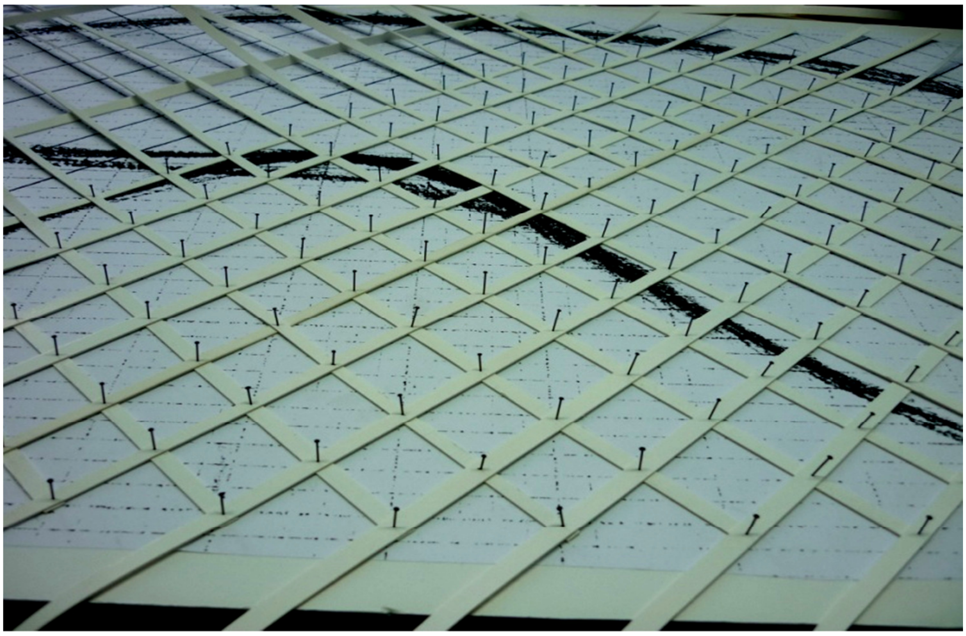

Fig 2. Flat Mat made from 5mm wide pastecard strips pinned at their intersections

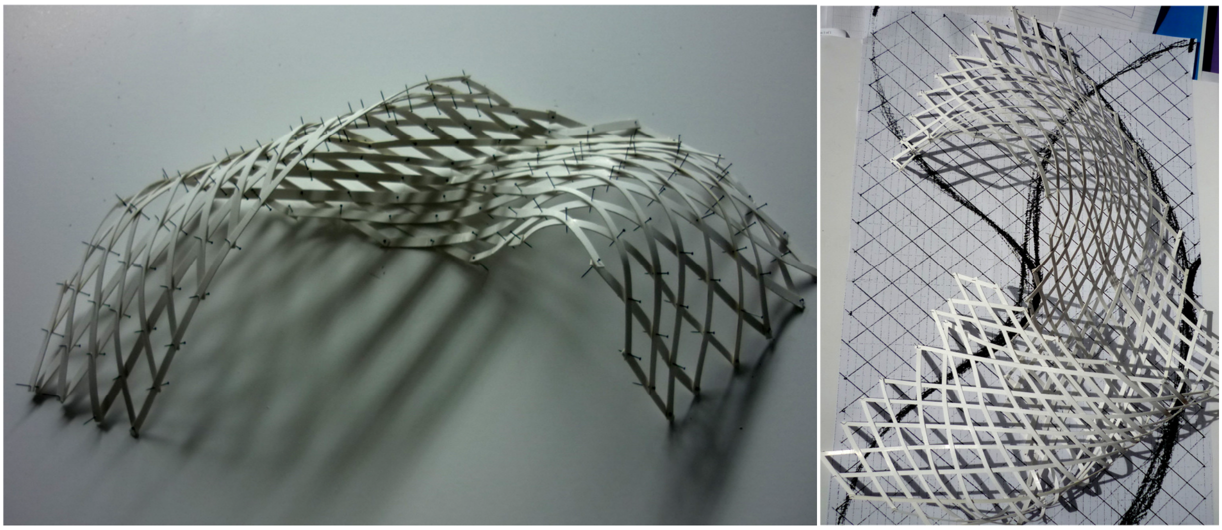

Fig 3a and 3b. The same flat mat is capable of deforming into different forms demonstrating reusability as concrete formwork.

The constructed mat is now able to perform in-plane deformation when forces are applied. This newly constructed mat was able to twist and deform 3-dimensionally. It is this 3 dimensional deformation that gives the mat the ability to define space, to rise from 2-d to the 3-d giving it the ability to define space and perform efficient load transfers - to become alive.

Playing with the grid-mat, it was noticed that the deformation noticeably depends on the pattern and arrangement of the grid. If a mat was constructed such that grid pattern are parallel to the mat edges, the deformation creates a narrowing effect where the deformed mat tapers into a point. However, to achieve useful deformations which produced a useful length and breadth dimension, the grid pattern needs to be at a diagonal. It was also noted that by pre-deforming the mat, e.g. by lengthening or shortening the mat, will help in the deformation process.

The paper grid mat was pushed and pulled into shape and secured into position by pins onto a foamboard base. By this, twisting forces are introduced into the structure. The twisting capacity of the timber was not tested, but its behaviour was cognitively observed, studied and understood by "playing" with this scaled model.

3.2 THE SWELLS - Morphology

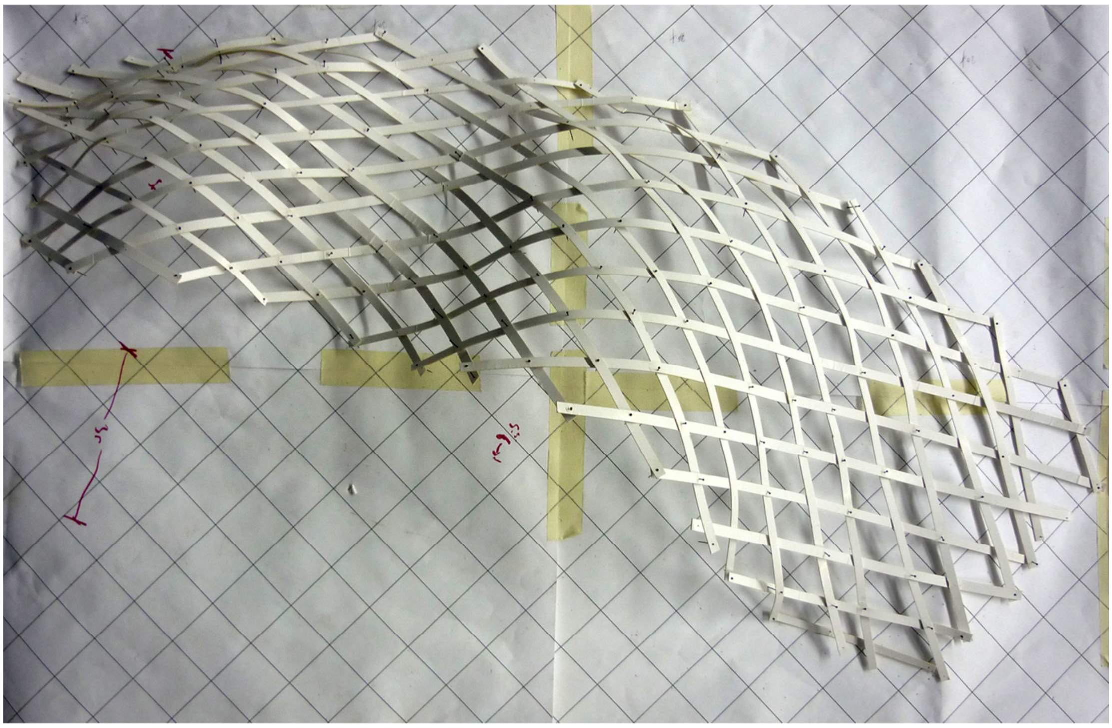

Fig.4 1:50 model of the gridshell THE SWELLS. The smaller crest is on the left and taller crest on right.

After much simulation tests, discussions, experimentation and explorations, the final design was arrived at. THE SWELLS, as the piece was eventually entitled, will be constructed from a rectangular grid mat measuring 7 units wide and 17 units long. Each unit being 900 x 900mm square diamond, this meant that the mat laid flat measured approximately 9m by 18m.

The designed gridshell consists of 2 swellings to the structure- the smaller *baby swell* appears at the western end and with the front edge leaping out of the ground to a height of 1.2m. The mat then dives into the ground again before rising to create *mother swell*, this time taller, to a height of 3.5m again with only the front edge rising out from the ground. All the back edges are anchored to the ground.

3.3 Sequence of erection

The mat is deformed by a specific sequence of erection. Firstly, the mat was constructed. Then it was rotated completely (without deformation) to the correct orientation. After that, the mat was elongated (deformed 2 dimensionally), so that the grid pattern deforms into diamonds from squares. The middle section between the 2 crests is identified and anchored down to the ground, so that they stay stationary. To create the *baby swell*, the short western edge of the mat moves southwards to push *baby swell* out from the ground. To create *mother swell*, the other short edge of the mat is similarly moved southwards to push it out from the ground. According to the 1:50 model, structure form acted in shell action, with most members acting in compression. The crests feel taut and are assumed to be acting mostly in compression.

3.4 The Construction

The final timber gridshell was constructed using 2.1m long pieces of timber pine battens of profile section 35 x 12mm arranged in a 900mm square grid. Each piece of timber is pre-drilled to create a couple of 5mm diameter hole at each end. They were then spliced together using nuts and bolts to create longer members. At the intersections, long flexible members were cross bolted at intermediate pre-drilled points to form swivel joints, replicating in-plane swivel action performed by pins in the paper card model.

Fig5. The simple testing rig to test the timber battens.

Testing of the timber was carried out by using a simple jig test. This required all the timber battens to be subjected to a bending test which required the softwood to be bent to a calculated curvature before it snaps. Breakages were rejected and occurred at 40% of the entire batch of pine softwood timbers. As expected, timber battens mostly failed at weak points specifically at knotted sections.

Fig6 a)Flat mat is carefully lifted and moved to correct orientation. b)the baby swell is visible at far end.

The timber mat was first constructed laying flat on the ground according to the scaled 1:50 model. To do this, battens are spliced and bolted together at their intersections. The card model proved a very useful tool to communicate to the student team as to the sequence of erection. Each student need know whether they are a) stationary or b) moving and if they are moving, in which direction they are moving. The sequence was choreographed by using the model in team meetings during the week.

When the mat is ready, the flat mat was pushed into shape by students holding on at important points. Each student either walked towards each other or away from each other to bring about the 3D deformation of the flat mat in accordance with the simulations of the scaled paper strips model.

Fig 7. a)The baby swell is fixed by pegging down. B) Bracing members are fixed to triangulate grids to lock in form.

Once the form of the gridshell is arrived, longer bracing elements of these timber members were drilled and bolted together to "fix" this shapes by triangulating the quadrilateral grids to induce form rigidity. A simple system of metal pins and timber blocks were used to peg the gridshell in place. Rope was also used to tether the structure to the ground to prevent wind uplift.

The structure allowed visitors to interact and walk and sit under the structure during lunch-hour and drew much interests from the media including local newspapers and the radio.

Fig8. The completed gridshell on display. The bigger crest (left) rises to a height of 3.5m.

4. Advantages of the System

The exhibit was left on-site for a 2 week period, inviting the general public to view and interact with the structure. It was disembled and kept for future re-erection. When the bracing pieces were removed, the gridshell flipped back to its original 2 dimensional mat form. The flattened mat was then collapsed, taken apart in sections and stored away. It was the intention to re-instate the mat and re-form it into another shape. Explorations made using the paper model proved it to be a feasible idea (Fig. x, y)

The mat is liken to a handkerchief which can be folded scrunched up in numerous forms. The idea that this is reusable is very attractive.

This workshop illustrates the fact that this system is effective in erecting a small-scale enclosure. This method of pushing to deform a flat lattice mat means that tall structures may be constructed without complicated scaffolding and ladders which is advantageous in any construction site, can minimise physical hindrances, thus increasing logistical efficiencies and consequently economy.

5. Evaluation and Limitations

The timber used was indoor grade pine sections. The structure remained intact with the good fortune of dry weather in the weeks of outdoor display. In the event of inclement weather, the structure may suffer from moisture deterioration and possibly fail. An alternative material may be investigated and explored, may offer a weather-proof solution to the creation of such structures.

The weakest points of the gridshell structure are observed to be at the regions of contraflexion – these are areas where a change of geometry occurs ie when the shell changes from a anticlastic to a synclastic geometry. These areas demonstrated the most deflection. Careful consideration need to be applied to the design of these regions.

The project focussed on the cognitive instinct of the designer in terms of material and structure. Structural analysis, calculation and finite element analysis may be useful to confirm/ testify/ enhance the design to complete the learning experience and to create a structure with mathematical soundness.

The erection process relied heavily on effective communication and teamwork. The design process is a very important, albeit time-consuming. This required the sensitivity to manoeuvre the fragile mat, susceptible to fracturing prior to gaining stiffness when it becomes form-active. There may be a limit to how large this grid mat can be. This also requires a large area to provide manoeuvrability of the long members on-site and may require either pre-fabrication or an appropriate setting to allow this manoeuvrability to feasibly take place..

5.1 Future Work and Development: Potential as Reuseable Formwork for Concrete Shells.

This method of building small scale gridshells intuitively can have an impact of the revial of shell construction. In recent years, computer advancements has revived shell structures into the vocabulary of 21st century architecture. This system of shell construction, reuseable in our sustainability conscious environments bears importance to the revival of these thin-shelled structures.

One application of the deployable timber lattice structure is surely the possibility of use as formwork for concrete shell construction. The deployable mat, not necessarily of timber, could be pushed and erected into shape. Fabric membranes are then laid onto this structure before concrete is sprayed onto the surface. Upon the new concrete shell being cured, the deployable gridshell can be moved to another location to create another shell form.

This is an ongoing research on the feasibility by the author as part of a PhD studies program at The University of Edinburgh.

6. Conclusion

The workshop presented in this paper proposes an exciting way of constructing shell forms and geometries using the scaled model as a starting point of structural investigation. It also exemplifies the creative pedagogy advocated by Nervi and Isler, that intuition and an understanding of material and their structural properties is an important aspect of architectural design in education.

The collapsible and deployable nature of this gridmat makes it suitable for re-use and its application as formwork for concrete shell construction is postulated to further propel the use of shell construction in contemporary architectural application with sound structural logic, economy and of sustainability.

7. Acknowledgement

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