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Timber gridshells: beyond the drawing board

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In March 2011, a week-long workshop that invited participation from all architecture and architectural technology students at Sheffield Hallam University, UK was organised with the objective of enhancing students' thinking and experience by construction thinking. It was aimed at creating a sense of realness to realise a design project collectively. Timber was set as the material of exploration. The students had to make use of bending to design and create a timber gridshell structure. This made use of a quality traditionally felt to be a structural weakness of the material. To do this, students form-found non-mathematically and non-digitally using paper gridmats. This paper describes the aims, activity and outcome of the timber gridshell workshop as a way of preparing architects and technologists of the future and introducing the challenges of architectural design in terms of economics and construction process, aesthetics, effective communication and structural intuition by working with a given material – all important aspects in achieving effective architecture.

1. History and development of gridshell architecture

Gridshells belong to the shell family of form-active structures in which load and span are linked to morphology (Figure 1). In principle, compression timber gridshells are created by deforming deployable timber gridmats with scissor joints. Similarities are identified with the latticed walls which make up the yurts of the Mongolian nomads, being re-usable, easily de-mounted and re-erected (Figure 2).

The word 'gridshell' was first coined by Frei Otto who led investigations into the design of engineered gridshells. The Essen project of 1962 built for the German pavilion was an experimental building that culminated in the Mannheim Multihalle roof for the German national flower show in 1976 (Happold and Liddell, 1975). Designed to be a temporary structure, it remains standing to this day.

There appeared to be a drought of gridshells constructed this way until the Weald and Downland gridshell near Chichester, England designed by Edward Cullinan Architects in 2002. Improvements in detail design and the construction process were made. Instead of being pushed upwards from the ground, as in the case of the Mannheim Multihalle gridshell, the lattice mat was lowered over a period of 3 months using an extensive matrix of specialist scaffolding. This was followed by the completion of the Savill Building in 2006 set within the Royal Landscape at Windsor designed by Glenn Howells Architects (Harris *et al.*, 2003).

As architects work with materials to create space, the understanding of structural principles and material behaviour becomes imperative. Architects do not work against gravity to create space. Rather, architects should work with gravity by understanding how effective force transfer can help to create efficient forms and bring economy and aesthetics.

With computer and digital advancement, structural analysis and reiterative design process have accelerated the process of formfinding. Prior to our present digital age, formfinding was carried out physically with hanging models. Historically, the catenary, as a mathematical concept, has seen the attention of great names from the history of science such as Galileo, Hooke, Leibniz, Huygens, Bernoulli and Euler, among others, and catenary arches have been used since ancient times in building and construction, as seen in the designs and construction of arches in the medieval era.

Formfinding of shells are closely related to inverted catenary curves and were used by Gaudi and Frei Otto in their work. Like Antoni Gaudi who spectacularly used hanging chain models to find the optimal shape for La Sagrada di Fagmilia (Figure 3(a)), Frei Otto used hanging chain models to study the optimal shape for gridshell structures to work structurally (Figure 3(b)).

The ways in which structure impacts on service co-ordination and space layouts are important considerations. Aesthetically, architects have responsibilities to inform and advise. To understand structural rationale is therefore to understand a correct way of building.

To take learning out of textbooks and formal lecture venues, the construction workshop reinforces theory lessons and

Figure 1. The swells of the timber gridshell structure against the backdrop of Sheffield

encourages on-site thinking, spontaneous problem-solving not offered by conventional methods of teaching and learning in the design studio environment.

One of the most successful structural artists, Pier Luigi Nervi expressed strong views about educating architects with regards to structure. In his 1965 writing for the Norton lectures at Harvard University, he opposed the dictation of mathematical calculations on structural forms – explaining creativity and structural intuition as important proponents of design. He emphasised the teaching of creativity and not only soulless statics. The behaviour of material can be taught and explained, but ultimately this can only be learned through seeing, feeling and understanding how material reacts to different loading conditions. Hence, only by experiencing this process of design and construction first hand, can learning of material behaviour effectively take place (Nervi, 1965).

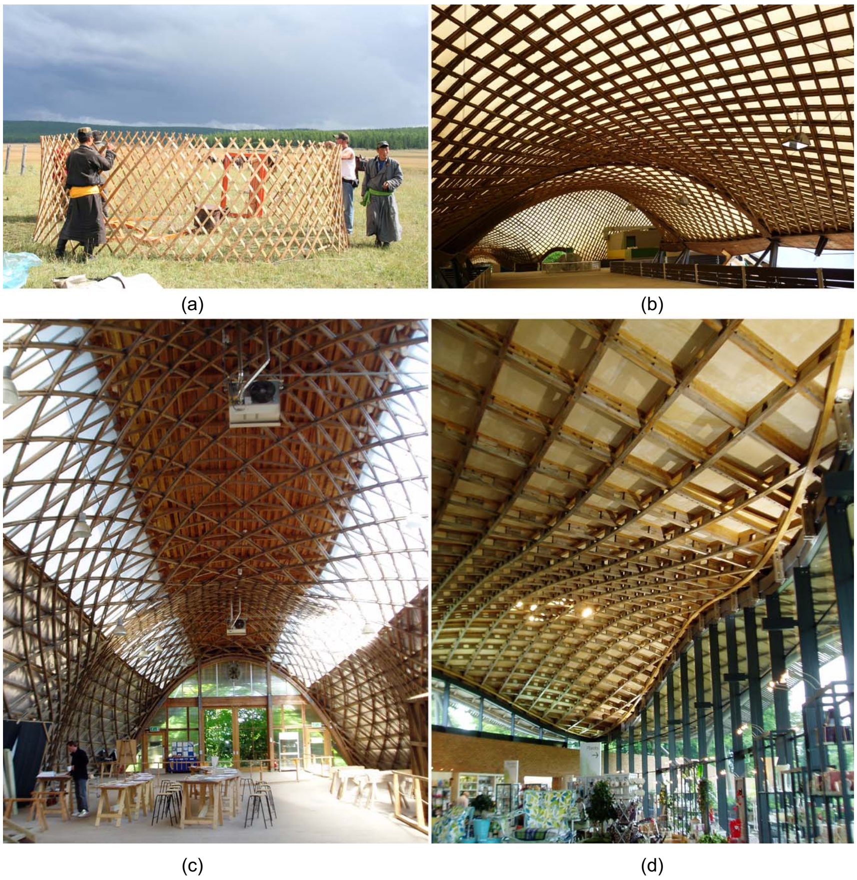
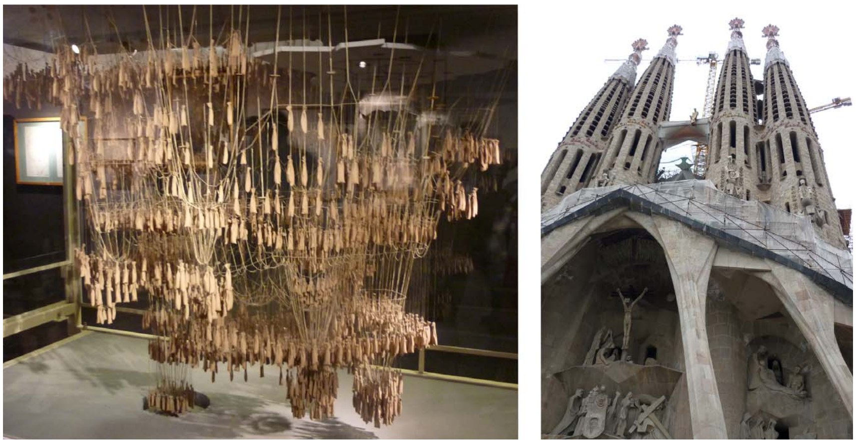


Figure 2. (a) Deployable timber lattice mats are used in the construction of yurts by nomadic tribes in Mongolia. [By Aloxe (Own work) (GFDL (http://www.gnu.org/copyleft/fdl.html)), via Wikimedia Commons]. (b) The Multihalle at Mannheim, Germany which was built in 1976 for the National German Garden Show still stands to this day. (c) Weald and Downland Gridshell by Cullinan's Architects completed in 2002. (d) The roof of the 2005 Savill Building in Windsor



(a) (b)

Figure 3. (a) The formfinding of La Sagrada di Fagmilia is based on principles of the inverted catenary, seen here as a physical scaled model. (b) La Sagrada di Fagmilia by Antoni Gaudi is constructed from masonry but derived structural geometry from physical formfinding using a scaled hanging model

Structural intuition can be developed through working with physical models. Historically, the physical model had allowed shell designers such as Eduardo Torroja y Miret to explore ideas in forms, in a time lacking in computational analysis. One of the most iconic piece of his work was the Madrid Hippodrome, the La Zarzuela Race Track, which had a 13 m shell roof cantilevering out 12·8 m (42 feet) forward from the main support and going back 7 m (23 feet) in the other direction (Figure 4(a)). The impressive looking structure hovered over the seats of the outdoor seating to a race track with steel reinforcement which resembled very gently curving folded paper. The concrete shell measured 50 mm (2 inches) thick on its free edge and hence had incredible visual lightness. The roof thickness gradually increased to 140 mm (5·5 inches) at the crown over the line of main supports. Investigation and the comprehension of the structure were made using physical models. Famously, Torroja studied the structural behaviour of the building by investigating the structural behaviour of a card model. This study allowed him to sketch out the approximate pattern of the internal stress which in turn informed the patterning of steel reinforcement bars within the concrete structure. With this expectation, a life-scale model was built and prototyped to verify and understand this unusual form. The contractors built a prototype module of this roof structure which impressively carried three times its design load. As it was a time when steel was scarce, the prototype unit was broken up and the reinforcement steel was used in the last module. It was so strong that during the Spanish Civil war, although 26 holes were caused by gun shelling, the structure remained standing! (Billington, 1982).

Structural intuition can be developed through life-size construction. Felix Candela, another luminary of the shell builders, built experimental concrete shells at life size to understand shell behaviour. His first major work was the Pavilion of Cosmic Rays for Mexico City University campus in 1951 (Figure 4(b)), believed to have brought him international renown. The shell was amazingly thin as it had to meet the strict requirement of a maximum thickness of 1·5 cm (Garlock and Billington, 2008). He was influenced by the way medieval master builders built Gothic cathedrals. Prior to this, Candela built experimental shells to test their structural behaviour and from then on this became his signature way of studying and understanding the structural behaviour of thin concrete shells. Being a very efficient structural form and with the ready availability of low labour cost in Mexico, he believed that building concrete shells was advantageous to him while practising in the intensely competitive construction industry in Mexico at that time (Faber and Candela, 1963).

Structural intuition can also be developed through 'playing creatively' (Chilton and Isler, 2000). Heinz Isler, another great shell builder, famously advocated that students maintain a child-like curiosity and creative outlook to nature and the phenomena around them. He applied this attitude of 'creative play' in his work as a prolific shell designer, form-finding physically using hanging models. This curiosity and observation of nature and phenomenology drove his distinctive exploration of forms as demonstrated by many of the thin-shelled structures such as the Deitingen service station roofs of thin shell concrete roofs in Switzerland (Figure 4(c)). (Chilton and Isler, 2000; Ramm and Schanck, 1993).

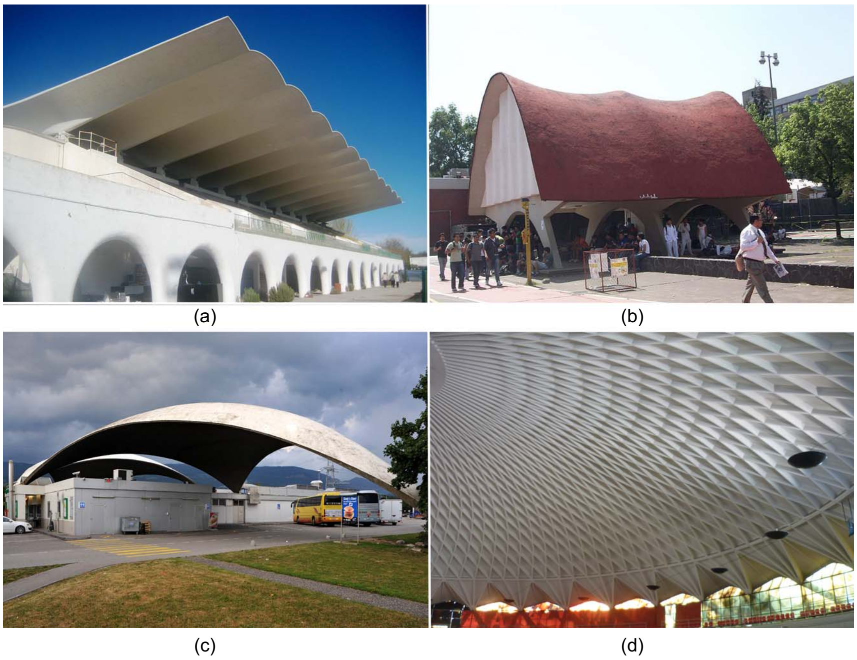


Figure 4. (a) Thin repeated concrete shells form the canopy of La Zarzuela Hippodromo roof by Torroja [By Outisnn (Own work) (GFDL (http://www.gnu.org/copyleft/fdl.html)), via Wikimedia Commons]. (b) Cosmic Ray Pavilion, Mexico City by Felix Candela (1951) [By GAED (Own work) [Public domain], via Wikimedia Commons Figure 5(c)]. (c) Deitingen service station roofs in thin shell concrete designed by Heinz Isler [By Хрюша (Own work) (CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0)), via Wikimedia Commons]. (d) Palazzetto dello Sport, Rome, Italy by PL Nervi (1956–1957)

2. The workshop: preparations, materials and programme

Construction workshops serve as an effective way of educating the architects of the future. Workshops that help students to learn have been developed in technology teaching at universities globally. At UNAM in Mexico City, construction workshop sessions are used to aid structural understanding (Oliva-Salinas, 2007). Structural learning are also guided by technology teaching via life-size construction workshops in Denmark (Figure 5) (Larsen *et al.*, 2010)

Understanding material, their tectonic, structural qualities and behaviour are crucial in an architect's education. The ability to consider the construction process in design is an important part of learning about the art of building.

A workshop to design gridshells by using a physical form-finding method therefore offers an opportunity to enhance the education of a young architect/technologist. The experience of life-size construction, with an end result that is both physical and spatial, is believed to reinforce communication skills, construction thinking and material sensibilities. The handling of material, the physicality of the activity and the tangible structure also simulate a realness and excitement in construction – not just an exercise restricted to pen and paper, drawing board or computer space. Importantly, construction workshops add value in terms of cognitive learning that broadens their architectural thinking, encompassing considerations of buildability and construction processes – a view shared by Carpenter in 1997 who wrote that

> structure, detailing, design issues, and construction strategy are all debated in the hands-on atmosphere of three-dimensional reality. The best architects understand the logic and poetics of construction and the best way to teach this is to build (Carpenter, 1997, p. 46, quoted in Jann (2009), quoted in Shannon and Radford (2011)).

A timetable that describes the activities of a week-long workshop held at Sheffield Hallam University, UK, in March 2011 is presented in the Appendix.

The workshop commenced with introductory lectures from invited guest speakers relating to the theories of gridshell and practical experiences from lightweight structure design and construction. It must be stressed that the presentation of basic principles of gridshell design is important to meet the learning

(a) (b)

Figure 5. (a) During a construction workshop in Denmark in 2010, students first designed the gridshell using a scaled model. (b) Using bamboo spliced together using plastic cable ties, the actual model was subsequently built using the physical model as a guide

outcomes. Various practical problems faced by previous designers were presented to achieve a broad understanding of problems and solutions encountered by their designers and builders. The lecture programme therefore provided instructions and a strong theoretical background and foundation upon which the ensuing practical construction could build.

Following these lectures, the students researched and designed the structure in teams by making physical card models. They then presented their designs to decide which design to build (Figure 6(a) and (b)).

Throughout the week, breaks from the construction activity took place in the form of supplementary lectures by various speakers.

The structure was designed and built by the students at the upper lawns in Sheffield city centre belonging to the University with advice, guidance and expertise from guest speakers who visited at different times during the week.

To anchor the timber gridshell onto the ground, a system of restraining pegs and wooden blocks were used. As such, 40 iron pegs made by the technical team by bending iron rods, diameter 8 mm, to J-shapes were prepared. In addition, 20 timber blocks measuring 190 mm × 70 mm × 45 mm with a notch 70 mm long and 10 mm deep was cut out from each block. Two holes of diameter 5 mm were drilled through at both ends as illustrated in Figure 6(c). These cost £100 to make.

Nine hundred and twenty pieces of softwood pine laths with section 12 mm by 3 5 mm and 2·1 m long were purchased from a local timber yard, costing £1000. They were pre-drilled with holes of diameter 5 mm in the technical studio to a pattern worked out by building a mock-up to test out the grid pattern. Nuts and bolts costing a total of £130 were purchased. Rope and miscellaneous materials cost £100. The materials were assembled using spanners and drills which the University already owned.

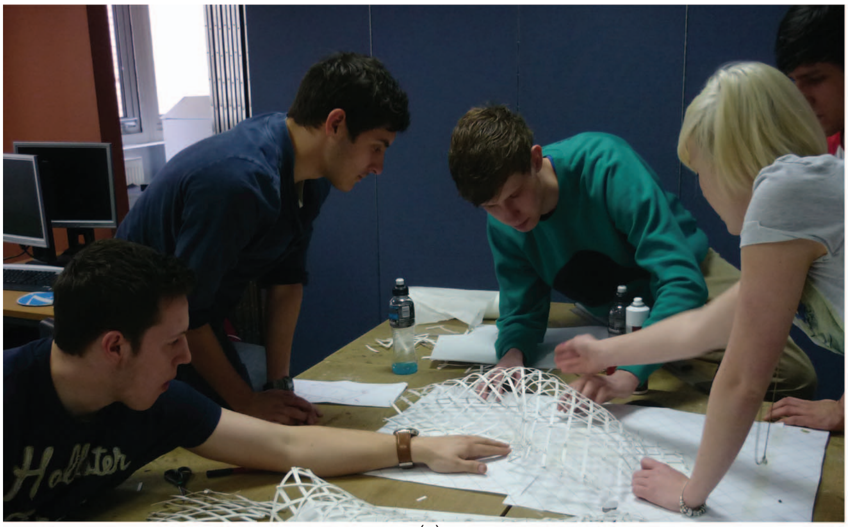
The construction used conventional materials in an unconventional construction solution and employed inexpensive material and tools that are readily available.

In total, the workshop cost £1330 for materials and preparatory labour.

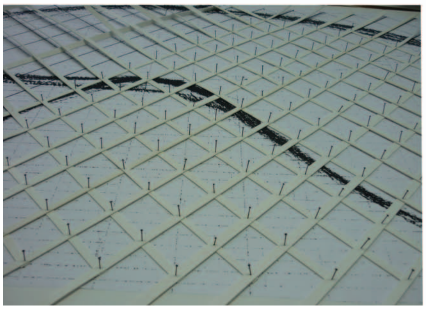
2.1 The workshop: design, testing, construction

To formfind and understand the behaviour of such structures, pastecard which was 1·5 mm thick was first cut into strips that were 5 mm wide. They were arranged in a lattice to form free scissor joints and pin-jointed to create a mat that could be deformed. The simple square grid was capable of deforming into diamonds, effecting a change of overall length of the mat (Figure 7(a)).

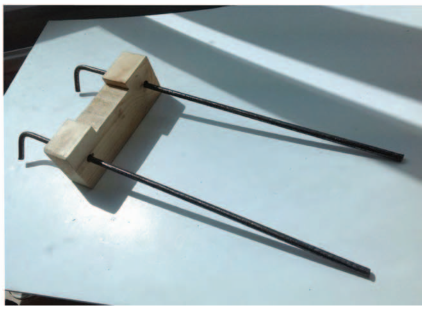
It was observed that the direction in which the grid was laid affected the behaviour of the mat. Initially, the mat in Figure 7(b) was made by laying a grid parallel to the edges of the mat. When pulled or pushed together, the rectangular mat transformed into a rhombus with two sharp-pointed opposite corners at a flat dimension.



(a)



(b)



(c)

Figure 6. (a) Physical model-making by workshop participants encouraged structural, architecture and constructional consideration. (b) The flat gridmat lattice was made by pinning paper strips at their intersection points. (c) The anchoring system consists of a timber block and iron pegs that are hammered into the earth to anchor the gridshell

To investigate the nature of deformation, an alternative mat with a diagonal grid orientation was made to investigate this mat behaviour. When compressed, the mat maintained the rectangular geometry. On the flat dimension, compared to the previous option, no sharp corners were formed (Figure 7(c)).

By deforming the grid, the overall dimension lengthened or shortened. Following that, by restraining specific points to the ground, pushing the mat from a flat plane can produce the three-dimensional shell illustrated in Figure 7(d). The material responds to the application of forces to create undulations and readjustments in the grid patterns to bring about three-dimensional deformation – with an understanding of material behaviour coming from the need to create architectural space.

This understanding and appreciation of mat behaviour was used to design the grid shell. By selecting specific points as stationary reference points, the mat can be pulled (by applying tension forces) or pushed (by applying compression forces). Subjected to these forces, it was possible to create spectacular three-dimensional grid forms exhibiting shell morphology from a flat mat (Figure 7(e)).

The design is then pinned down onto a polystyrene board. Eventually, a mat at 1 : 50 scale was made as this was judged an appropriate scale to allow transformation deformation to be workable and visible (Figure 7(f)). For expediency, it was assumed that the behaviour in the card strip model would equate and translate in principle into timber laths at the actual scale.

The grid size of 900 mm square was determined by the length of the actual timber laths and also the overlap splicing dimensions to allow the mat to become buildable with the 2·1 m timber laths.

Without mathematical calculation and verification, students could understand how grid orientation affected the behaviour

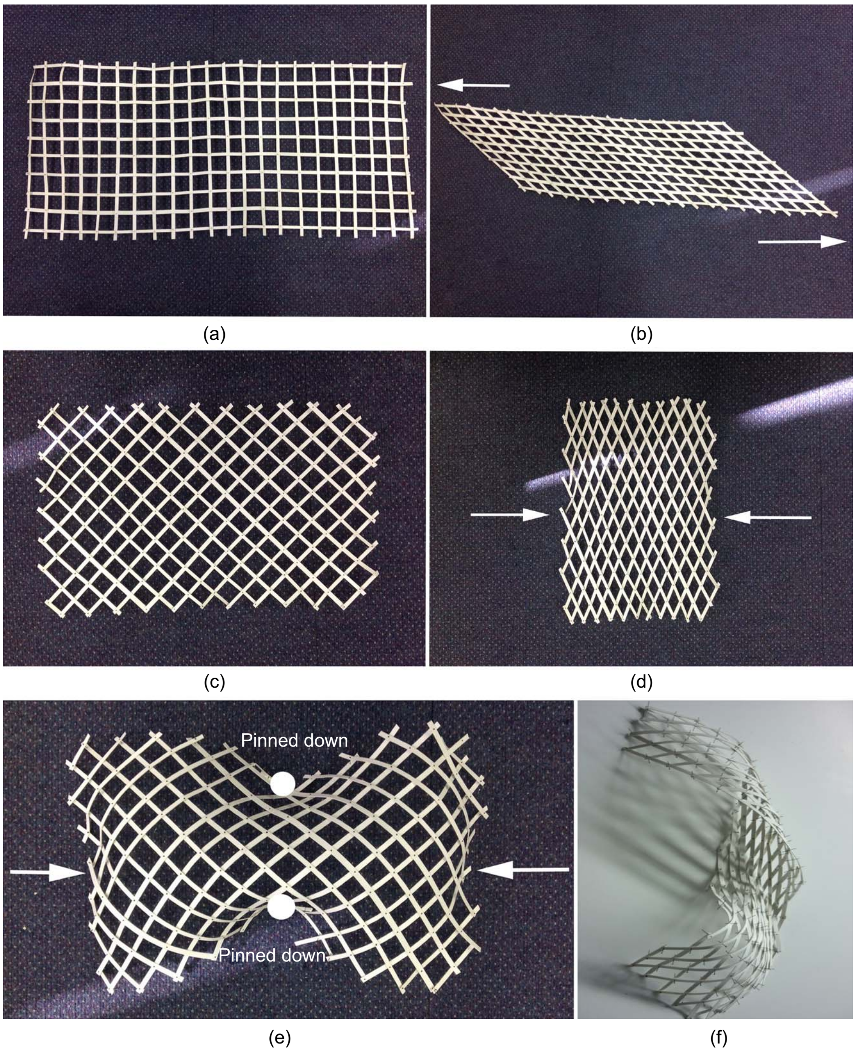


Figure 7. (a) Original flat latticed mat. (b) Original flat latticed mat has transformed into a rhombus when forces according to arrows are pulled. (c) An alternative lattice mat with a diagonal grid pattern. (d) The mat closes up when in-plane forces are applied, retaining mat dimension. (e) Simple three-dimensional deformation can be achieved by fixing specific points and applying compressive forces to a two-dimensional pre-deformed flat mat. (f) Experimentation of form design with physical deployable gridmat models applying principles of deformation helps to achieve sophisticated geometries, most displaying shell action

of mat deformation. The students learned how three-dimensional deformation could take place by deforming the flat mat first, then pulling (tensioning) or pushing it (compression) to achieve deformation in three dimensions (Figure 8(a)). The participants were able to see, feel and understand the forces acting within the deformed mat to exhibit shell action. Playing creatively and objectively with the lattice card mat was imperative to understanding material behaviour of the mat – one which differs from that of their constituent timber laths.

Material failure tests (Figure 8(b)) were carried out to check for the suitability of pine laths. They went through a simple jig test to check that the timber could be bent to an arc of 2 m radius without snapping. A natural material, timber laths contain knots where the laths broke during testing. Following the tests, 40% of the timber material failed (snapped) and were rejected.

2.2 The design: the swells

By manipulating, studying, making and subsequently understanding the gridmat, it was noticed that for the mat to become usable when stretched, the grid pattern had to be diagonal as this deformation did not produce sharp pointed corners which rendered the mat less useful.

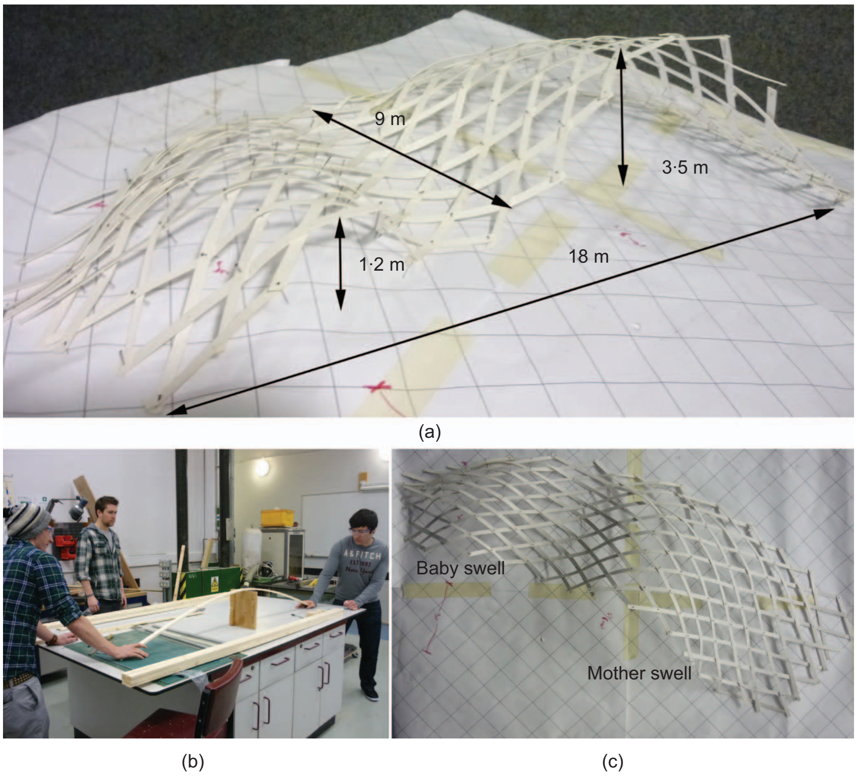


Figure 8. (a) The eventual structure consisted of two swells, the first rising to a height of 1·2 m and hence called 'baby swell'. The second rose to a height of 3·5 m and correspondingly was called 'mother swell'. (b) The timbers were tested using a simple failure test jig. (c) Plan of the installation in terms of a 1 : 50 scaled model of the swells

The designed mat measured 18 m (17 grid units) long by 9 m (7 grid units) wide with each grid measuring 900 mm square. The final shell design consisted of two swellings which rose from the flat plane. Both of these swellings had their front edge rising out of the ground. The swellings were asymmetrical. The smaller 'baby swell' rose to a height of 1·2 m and the bigger 'mother swell' rose to 3·5 m.

2.3 Constructing the swells

Describing a construction process three-dimensionally to coordinate teamwork verbally can be confusing and not effective. The paper model allowed the design team to quickly see, discuss, work out and choreograph the transformation and sequence of erection stages. Through the initial material behaviour investigation, it was noticed that the mat actually benefitted from being stretched to 'loosen up' the joints.

The construction stages scheduled were

(*a*) construct the mat in a square grid
(*b*) stretch and lengthen the mat by deforming the grids into rhombi on the long dimension
(*c*) rotate the mat to position as a flat mat
(*d*) fix the points of the valley (area between the two swells)
(*e*) move one end of the mat to compress the mat to form baby swell
(*f*) fix down points onto the ground to fix the shell
(*g*) move another end of mat and lift to form mother swell
(*h*) fix down points onto the ground to fix the shell
(*i*) brace and triangulate structure to stabilise and stiffen the gridshell.

2.4 The actual construction

A short time-lapse film of the construction can be viewed online using the following URL link: http://vimeo.com/21348054.

The students first formed the mat on the ground according to the model (Figure 9(a)). The entire mat was then stretched and lengthened. It was then moved into position (without deforming). The valley region between the two swellings was identified first and was fixed to the ground and held in place by steel chairs and timber blocks.

The baby swell was created first, by shifting the mat to form a swell in the mat. As predicted from the physical model, the edge of the mat rose up from the ground. This baby swell was

Figure 9. (a) The gridmat was constructed flat on the ground by splicing timber laths. (b) The gridmat was stretched and shifted into position. (c) The gridmat was compressed to form the baby swell. (d): The mother swell is formed

fixed onto the ground. It was subsequently fixed into position by fixing bracing pieces to triangulate the structure and thereby freezing the geometry.

The mother swell was formed in a similar way (Figure 9(b) and 9(c)) – students held specific points and by moving towards or away, the bigger swell was created. This time, it rose to 3·5 m and was fixed similarly using metal chairs and timber blocks. Bracing pieces were bolted together from the timber laths and fixed to triangulate and stabilise the entire structure (Figure 9(d)).

3. Evaluation

The process of construction addressed many important considerations of structural design and construction thinking. In this exercise, it was easy to create single long flexible members from card at 1 : 50 scale. When scaled up, the students had to think about how a single continuous element can be achieved from 1·2 m long timber laths.

Transportation logistics was an important point to consider. The shorter 2·1 m timber sections allowed the timber to be transported in lifts and carried around staircases to the lawned areas. Longer laths would create difficulties in transporting the fragile material. In fact, this same issue of portability arose in previous constructions of timber gridshells. In the Weald and Downland Gridshell by Edward Cullinan's Architects, shorter timber sections had to be scarf-jointed under a poly tunnel cover to be kept dry. Using the drop-down system, the timber members had to be first transported up to a high roof level to create a gridmat before being dropped into position. This was managed ingeniously by sliding them through a hollow poly pipe (recorded interview with Corbett, 2009).

In such projects, communication is the key, requiring effectively a creative, collaborative and reiterative respect and relationship between the architect, the contractor/builder and the engineer. In this hands-on workshop, the students took on a tri-partite role, appreciating and empathising with the importance of each party in the realisation of such a project.

In this workshop, mathematical analysis was deliberately de-prioritised to induce the freedom for intuitive design for structural correctness in geometry and morphology. Structural correctness was crucial in the design of form-active shell structures where stiffness and stability depended on having correct geometry and morphology. Shell stiffness and stability were controlled by increasing or reducing the curvature of the structure – a structural behaviour that the students learned through designing and building (Figure 10).

Figure 10. (a): The geometry of the structure was stabilised by bracing and triangulation. (b): The swells nearing completion. (c) The swells on display at Sheffield City Centre

The model card mat and the actual timber mat exhibited similar structural characteristics of bending. Although no mathematical calculation was used to verify the structural behaviour, the students could see and feel the structural behaviour of the gridshell when it eventually produced a stiff shell form. The two-dimensional deformation corresponded with structural predictions provided by the scaled model. At regions of contraflexion where geometry changes from a synclastic to anticlastic geometrical form, these flatter areas, as expected from observing the model, were prone to deflection and felt 'floppy'.

By the same token, the limitation of this exercise was also laid in the lack of computational and mathematical verification. However, it demonstrated how such a workshop could instil *structural intuition* in the future and giving an insight and experience in using models and real-size construction to design structures in the future. Along the way, and inevitably, the workshop allowed students to understand the abstract but reiterative relationship and impact forms impose on structural rationale and vice versa, therefore appreciating material behaviour architecturally.

3.1 Taking down

The structure was taken down after 2 weeks of display on the grassed area. Being outdoors, the untreated pine wood would have been affected by temperature and humidity changes during different times of the day and night, as well as sunlight over time. During the fortnight, fortuitous weather meant that the structure did not get wet which would otherwise have drastically weakened the structure.

When the rope tethering was removed and bracing timbers unbolted, the structure sprung back into its original flat position. It was possible to deploy the structure again and close up the structure into the original position. The flattened mat was taken apart in sections, removed and stored – ready to be erected and used once again on another occasion. This demonstrates the potential of reuse and therefore recyclability of such a lattice mat.

4. Conclusion

The workshop proved invaluable as a learning resource of not only understanding construction materials, but also understanding various aspects of construction and architectural pedagogy which is fundamentally experiential-based. The workshop was an exercise of experiential learning (Kolb, 1984) where abstract concepts and generalisation were introduced during the first lectures. The testing of the concepts in a new situation takes place when the students design by models and envisage all the problems experienced designers encounter. The concrete experience of actual construction allowed the students to learn from their construction exercises, solving spontaneously as the construction took place. Eventually, the observations and reflection stage begins as they quickly learned and were able to apply their new experience in a future situation, perhaps in the designing of a timber gridshell in the future.

The construction and material behaviour portrayed an unusual perspective to material use – bending – considered by many as an inherent weakness of timber. In this instance, the shortcoming becomes a desirable property for a timber gridshell. This was an unconventional way of using timber. Like plywood and glue lamination manufacturing in which layers of wood are glued to form an engineered construction material with more structural control, this construction process made use of bending and flexibility of timber.

In fact, this was first described as the originator of the construction of the forest buildings of Hooke Park – the free availability of saplings in the forest which grew weak among the stronger and straighter-growing trees in managed forests (Herzog *et al.*, 2004). The construction of timber gridshells was borne from a sustainable technology of construction – by using a carbon neutral resource, which otherwise will become a waste product of forestry.

The workshop was an enlightening way of allowing students to experiment and construct a structure and experience the interaction between material, the designer and builder. This offered an invaluable platform for the architecture student to communicate by drawing, model-making and allow them to develop ad-hoc solving problem skills and learn about materials. This exercise emphasised the importance of the physical model-making to bring designs out of the drawing board. Such construction workshops continue to have an impact on curriculum teaching and learning in the education of an architectural professional of the future.

Acknowledgements

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Appendix

Timber Gridshell week-long workshop, 15–18 March 2011: activity programme

Times	Activity and Lectures			
Day 1: Tuesday 15 March (G.T., J.R., G.H., G.C., R.H.)				
10.00–10.15 a.m.	Introduction and welcome			
	Professor Sylvia Johnson: Dean of Faculty of Development and Society, Sheffield Hallam University			
	Gabriel Tang. Senior Lecturer in Architecture, Department of Architecture and Planning, Sheffield Hallam University			
10.15–11.00 a.m. (45 min)	The Challenges of Form Making in Timber			
	Gordon Cowley, Director, CowleyTimber Work, Lincolnshire, http://www.cowleytimberwork.co.uk/			
11.00–11.45 a.m. (45 min)	Timber Gridshell Construction			
	John Romer, Architect and Structural Engineer at Edward Cullinan Architects, London, http://www.edwardcullinanarchitects.com/			
11.45 a.m.–noon	Workshop programme and activities briefing			
	Gabriel Tang (15 min)			
Noon–1.00 p.m.	Lunch break			
1.00–6.00 p.m.	Scaled Model Design Workshop			
	Group A	Group B	Group C	Group D
	Norfolk 404,405,406 (Hub rooms next to the new resources room)	Norfolk 407 (new resources room)	Surrey 5309/5310 (old resources room)	Surrey 5309/5310 (old resources room)
Day 2: Wednesday 16 March (G.T., J.R., J.C., R.H.)				
10.00–noon	10.00–10.30 a.m.	10.30–11.00 a.m.	11.00–11.30 a.m.	11.30–noon
Presentation of Designs and Discussion	Group A (30 mins)	Group B (30 mins)	Group C (30 mins)	Group D (30 mins)
Noon–5.30 p.m.	Revisions of Designs and Actual Real Size Construction			
5.30–6.00 p.m.	Tidy Up			
6.00–7.00 p.m.	‘Heinz Isler’s Infinite Spectrum: Form-Finding in Structural Design’			
	SHU Evening Guest Lecture by Professor John Chilton at Pennine Theatre			
Day 3: Thursday 17 March (G.T., R.H.)				
8.00 a.m.–6.00 p.m.	Real Size Gridshell Construction on Site			
Day 4: Friday 18 March (G.T., G.C., R.P.) Take down: Friday 4 April 2011				
8.00 a.m.–4.00 p.m.	Real Size Gridshell Construction (site to be cleared out by 4.00 p.m.)			
10.00 a.m.–4.00 p.m.	Dissembling of the structure and materials stored away.			
4.00–5.00 p.m.	The works of Eladio Dieste – a lecture by Professor Remo Pedreschi			
	Venue: Peak Lecture Theatre			
5.00–5.30 p.m.	Feedback and discussion			
5.30–6.00 p.m.	Discussion on site			

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