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introduction

Molluscs are astonishingly diverse. Many species have a highly efficient shell that offers structure and protection, formed with minimal material thickness. What if we, as architects, designed with every material as if it were extremely valuable and scarce? Shell Lace Structure celebrates lightness, strength and economy. It utilises the least amount of material to do the most work. It understands that all materials are precious.

Shell Lace Structure is a tailored, single-surface structural technique invented by Tonkin Liu in collaboration with engineers at Arup. Mediating between the intuitive and the analytical, it embraces advanced digital design, engineering analysis and manufacturing tools alongside plasticine, paper and scissors. Shell Lace Structure integrates the structural principles expressed in 500 million years of variation in shells, the ancient art of tailoring, and cutting-edge technology. As a process, it seeks to close a schism that currently exists in architecture between research and practice, hands-on and digital, structure and form, economy and beauty.
origins

Shells

Five hundred million years of evolutionary development have spawned 93,000 extant, described species of molluscs. Through variation and adaptation, the Phylum Mollusca has grown to become a vast collection of species that vary in size, anatomical structure, behaviour and habitat. Such diversity offers a broad array of highly refined shell structures that achieve maximum protection with minimum material thickness, thus optimising the relationship between strength and form. Accretion of the shell from the mantle edge of the mollusc can be a complex and energy intensive process. Evolution has often optimised the efficient production of shells.

The iterative process of optimisation has yielded organisms that exhibit strength in both form and material, the efficiency of which outperforms most manmade structures. In architecture, there are lessons to be learnt from the three-dimensional structural principles of shells. Tonkin Liu sees nature as a tool to inspire, inform and improve the structure and forms developed through design.
In the past, many craftsmen, architects and engineers have employed shell structures for both reasons of structure and aesthetics. Two thousand years ago the first domed shell structures, including the iconic Pantheon in Rome, were built in a period of large-scale construction known as the Roman Architectural Revolution. Other shell-like structures can commonly be found in gothic architecture and in the more modern context of structural expressionism.

In the fifteenth century, the late flowering of gothic architecture in central Europe yielded the diamond vault. These concave vaulted structures, whose complex play of light and shadow bring a surprising puritanical modern aesthetic to the late gothic tradition, are formed from prismatic multifaceted surfaces. The brick construction technique and the faceted form produces an elaborate three-dimensional structure formed from surfaces that curve in only one direction. Triangular beams radiate out from freestanding columns or diminishing corbels on plane walls, bifurcating to create a web of intersecting crossbeams that deliver forces laterally across the surface.

13 Franciscan Monastery
Photograph of a late gothic diamond vault in Bechyne, Czech Republic.
The term ‘Surface structures’, proposed by Angerer, describes structures where there is a correspondence between the inside and the outside, the inside space and the external form being almost identical and separated only by the thinness of the construction itself. His classification sought differentiation from forms derived from the ‘solid’ or the ‘skeleton and skin’. Surface structures occur frequently in nature but only started to appear in buildings in the early 20th century. We normally call them shells, but the term also applies to other forms such as lightweight tensile membranes pioneered by Frei Otto. At this time two factors seemed to contribute to the development of shells.

In 1865, Karl Culmann introduced graphic statics, a graphic technique used to represent the resolution of the forces in a structure. It became a design tool which allowed the rapid development and refinement of the form to either control the forces themselves or to manipulate the geometry of the structure.

“It would be difficult to overestimate the impact of graphic statics on the world of structural engineering; it was certainly no less significant than the impact of the computer in the late 20th century” – Addis

The second factor was the development of reinforced concrete, patented by Hennebique in 1892. Although the system he patented was effectively a skeuomorphic derivative of the iron post and beam, the use of reinforced concrete increased rapidly. Soon many designers looked beyond his patent to explore the ideas offered by a liquid, plastic material that can find its own form.

The material and the methods of analysis produced new forms of structural expression and structural efficiency and made virtue out of the economic. The catenary is the shape that a suspended cable will adopt under its own weight. It can only carry force through direct tension and self-organises to find the most efficient shape. Inverting the cable produces the equivalent form but the forces are in compression, an ideal condition for concrete. Graphic statics allowed designers to explore the catenary to produce optimum geometries expressed primarily through their thinness. In Switzerland in 1925 Robert Maillart designed the Valtschielbach Bridge, a concrete arch of considerable thinness (varying from 23 to 29 centimetres). The thickness varied in accordance with the forces in the arch, which spanned 43 metres.
Through the history of architecture, there exists a clear correlation between the advancement of design and fabrication tools and the development of form. To begin with, each epoch struggles to find uses for the new tools it has created. As understanding develops, material can be given new form through new tools, finding a new language of construction. Today we have an array of digital modelling aids that allow architects to construct easily editable complex geometries in a virtual world. These digital models can then be translated into the physical world with incredible accuracy using Computer Numeric Control (CNC) fabrication equipment such as laser cutters and robotic actuators to machine and form building materials into architecture.

Good design uses the tools of the time to synthesise a material with a technical agenda. Tonkin Liu’s agenda is to delight through efficiency – using the least to make the strongest form. The design process begins with making. Using modelling clay, the design team tests forms using the thinking hand in a responsive and interactive thought process. The constant rolling and kneading of the malleable material aids concentration as possibilities...
Crafting Shell Lace Structure

by Harry Charrington

It was the wit of the Shell Lace Structure technique that struck me the first time I saw it; its inventiveness and economy setting it apart from the ever-growing herd of image-driven parametric projects. In contrast to the dogmatic application of formulas that restricts so much structurally- or computer-led architectural design to shape-making, Shell Lace Structure is determinedly architectural, and deployed and developed in relation to the specific character of each project; the nature of the site, the narratives of history, and the desires of users. It is also ingeniously designed and engineered to minimise its carbon footprint.

At the heart of Shell Lace Structure is an iterative artistry which synthesises observations of natural forms and geometries, traditional craft and fabrication, and advanced computer modelling and engineering, to conceive genuinely innovative (and for once I think the word is justified) forms. In five years of endeavour Tonkin Liu have developed a rigorous method of seeing and suggesting, measuring and testing, that has led to a series of realised and unrealised projects at the cutting edge of single surface structural design. This process now seems to be almost intuitive, and reminiscent of Friedrich Schiller’s argument that it is only through play that an artist can reconcile the demands of the rational and the sensory – and thereby achieve freedom:

“The mind, then, passes from sensation to thought through a middle disposition in which sensuousness and reason are active at the same time.” – Schiller

Such play is reciprocal and generous; each part of the process informs and responds to other parts, and there is an invitation to others to join in. Perhaps nowhere is this more evident than in the crafting of their work. Just as their play brokers no distinction between analogue and digital modes of drawing and modelling, neither does it between traditional and digital modes of prototyping nor fabricating.

Too often, in some melancholic appreciation of an object, we think of craft as a synonym for a rose-tinted past that can never be recuperated. But craft is an attitude; a way of doing things whose distinguishing attribute is taking pleasure in the life and resistance of materials and processes, and welcoming their implicit provocations to new ideas and forms. Just as Shell Lace Structure is not inspired by lazy approximations with natural organisms, but rather by a biomimetic study of...
The Shell Lace Structure technique was first conceived in response to the ‘Next Wave: Shelter & Kiosk’ open design competition for Bexhill-on-Sea. The competition, organised by the Royal Institute of British Architects, sought designs for a series of high-quality beachfront shelters that would contribute to the regeneration of the local seafront.

The design intent was to make a strong, doubly curved, vaulted form that would provide shelter from the wind and rain. This would be fabricated from thin, lightweight and durable aluminium sheets. The twisting, contorted series of arches, curving walls and part spirals was inspired by the strong forms of shells.
progression

Shell Lace Structure has been developed over five years of experimentation and cross-disciplinary practice-based research. Collaborations with structural engineers at Arup have enriched and guided the innovative structural technique. Collaborations with others in the fields of pattern cutting, fabrication, biomimicry and evolutionary biology have allowed the research to be lead in new directions and its outcomes to evolve with every design iteration. This multi-scaled, multi-cultural, and multi-disciplinary method of practice suggests that further collaborations could offer opportunities to take the project closer to its aim: to use the technique to construct civic-scale architecture.

The practice-based research is informed and driven by design competitions that provide the vehicle for iterative development. Just as organisms evolve in the natural world, each design brief poses new challenges for Shell Lace Structure, encouraging an evolutionary design process through variation, optimisation and adaption. The result is an ultra-lightweight, economical and expressive new breed of architecture.