Timber Wave

An installation in American red oak for the London Design Festival 2011 at the Victoria and Albert Museum

Designed by AL_A
Engineered by Arup
Made by Cowley Timberwork

Introd uction

I am delighted to introduce this publication, looking at the ideas behind the Timber Wave installation for the London Design Festival, and at the process of designing, making and installing it. For the London Design Festival it brings together two of the most important strands of our work – the commission of special structures by the UK's leading architects, and our relationship with the Victoria and Albert Museum, acting as the hub for the festival for the third year.

It is particularly exciting for us that this structure is outside the museum, and in the most visible and important place, framing the main entrance. All visitors to the museum will see it and pass through it, whether or not they are visiting installations and events related to the London Design Festival. And since it has such a great presence on the street, offering different views from different angles, it will also be seen by those who are passing the museum, whether on foot, by bike, by bus or by car.

It is therefore helping us in our aim of making the Design Festival as visible as possible in the city, and to involve as many people as possible in our programme. Design is about both ideas and their realisation, and the Timber Wave shows what can be achieved by close collaboration. I would like to thank and congratulate everybody involved in its realisation – such projects are never easy, especially on a tight time frame, but the result has certainly been worth it.

Ben Evans, director, London Design Festival

Making a wave

Ambitious and beautiful, the Timber Wave introduces new thinking and techniques

The massive but light and sinuously curved timber structure framing the entrance to London's Victoria and Albert Museum during and after the London Design Festival in September 2011 is special in many ways. A virtuoso piece of design by Amanda Levete Architects (AL_A) and engineer Arup, it is an investigation of just how far the technology of designing in wood can be pushed. It is also a showcase for American red oak, an abundant timber that is under-used in Europe. And it is a demonstration of collaboration not just between architect and engineer but also with the museum and with Cowley Timberwork, the specialist company that made and assembled the structure known as the Timber Wave.

Designed specifically to sit on the steps in front of the museum's main entrance, and to frame the decorative entrance to the museum, the 12.5m high Timber Wave is the most immediately visible sign that this is the third year of collaboration between the museum and the London Design Festival. Victoria Broackes, who is head of the London Design Festival at the Victoria and Albert Museum, said, "We are absolutely thrilled to have a major installation on our doorstep." It acts as an advertisement for the fact that in 2011 the museum is hosting 12 installations and around 50 talks and events.

But it is doing so much more. The design team started working on ideas in Spring 2010 (their original hope was to make something for the 2010 London Design Festival) investigating different ways of making a timber structure that could be self-supporting. Very different from most timber structures, the Timber Wave is made from a family of small elements which, despite their detailed differences, show a clear amount of repetition.

The Timber Wave is essentially composed of chords and braces, a fairly simple idea to create a stable structure, but in this case the architect chose to curve all the elements, so that it is no longer easy to 'read' how the structure works. Instead, one sees a delicate tracery, with the largest elements at the bottom, becoming lighter at the top as there is less weight to support. Again, unlike most buildings, where the structure is there to hold up the enclosure, in this case


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the structure is the installation itself, an idea that is closer to the way in which a bridge is designed, rather than a building.

There had to be a great deal of to-ing and fro-ing between the architect and the engineer. The architect used clever design software to come up with the forms that it wanted, and the engineer then had to calculate whether these would be structurally stable. If there had to be changes in the engineering, then the architect had to rework its design – and send it back to the engineer for further calculations.

Because of the curves and the way that the elements came together, it was also necessary to design some complicated joints, using as little steel as possible, to keep the integrity of the timber structure. When designing theoretically, it would be possible to make every single element and joint of the structure different – but this would be a nightmare to manufacture. So a degree of standardisation was introduced, in terms of the thickness of the elements and the curves, without losing the quality of the original design.

Because thick pieces of timber will not curve, and the curves on this structure are tight, the chords had to be made from thin slices of timber (lamellae) that were curved and glued together – a well-known structural solution known as glued laminated timber, or glulam for short. Further rationalisation had to be carried out at Cowley Timberwork, to make sure that it was possible to manufacture the elements effectively – and that it could be done within the very tight time frame.

There was also testing during manufacture of the Timber Wave, to ensure that the pieces would actually fit together, and that the elements and connections were as strong as calculations had suggested. Fortunately they performed even better than expected, largely thanks to the quality of the timber. The small elements were assembled into nine large pieces, which were brought to London and assembled on site in the week before the London Design Festival opened.

The Victoria and Albert Museum celebrates the craft of making objects, as well as the finished object itself. With the Timber Wave, which in completed form framed the museum entrance so beautifully and gave visitors a new perspective, it is appropriate therefore to look at how it was designed and how it was made as well as admiring the finished object. This publication offers an insight into that process.

“It is an investigation of just how far the technology of designing in wood can be pushed”

Architectural insight

The Timber Wave has provided Amanda Levete's first opportunity to work with wood at this scale – and she has relished the challenge

Amanda Levete is the founder of AL_A, a practice she set up in 2009, having formerly been one of the founding partners of Future Systems. Her practice has projects at all scales from furniture to major buildings, including a new building for the Victoria and Albert Museum (awarded after her appointment to design the Timber Wave). She is married to Ben Evans, director of the London Design Festival.

Have you designed in wood previously?
We have never worked with wood at this scale before, or used it as a structural material. I have always wanted to, but it has never happened, for whatever reason. I love laminated timber beams, and I love the very human properties of wood, the unpredictability of the grain and the pattern that wood has.

How did this project come about?
AHEC (the American Hardwood Export Council) specifically asked that we did the project. They have been following our recent work, including our own house where we have American hardwood flooring. We started working on ideas for the project last year.

What were the main challenges?
The entrance to the Victoria and Albert Museum is vast and grand. How do you respond to that and to the steps, and to the fact that it all goes inward? We wanted to bring the museum onto the street, to make a reference to the form of the arch – from a certain angle the Timber Wave appears to mirror that arch.

We also wanted to demonstrate the technical and conceptual properties of the material. Normally I feel uncomfortable if a design doesn't have a function at its core, but the purpose here is very clear: to create something that is self-supporting, that is made out of timber with minimal steel connectors, that goes 12.5m high and doesn't need to be tied back to something.

Tell me a little about your solution.
It's about the idea of repetition, and how you achieve complexity through repetition. We used furniture-making techniques on a large scale, to respond to the decorative

Image: Peter Guenzel

“ We wanted to demonstrate the technical and conceptual properties of the material ”

and didactic tradition of the Victoria and Albert Museum.

There are a lot of different things at play. We wanted to be transparent, to offer different views, so that someone coming along Cromwell Road would be aware that something is going on that makes the museum different for a short period of time.

The main material of the installation is American red oak. How did you feel about working with that material?

There is the beauty of working with a natural material – the perfection lies somewhere deeper, not in the evenness. AHEC finds it interesting that American red oak can be given a low impact oil treatment, which makes it more durable for exterior use.

What have you learnt from this project?

That it's about understanding the importance of working with this timber as a structural material.

Design

Projects such as the Timber Wave push design and engineering skills to the limit – providing both challenges and joys. It required communication skills that were as finely honed as technical ability. Architect and engineer worked together in an iterative process as every technical requirement had to feed back into the form of the structure, and every change in appearance affected the structural calculations. Fortunately, structural data already existed for American red oak and the timber quality was so high that it exceeded expectations.

American red oak

It is time for an abundant but under-used material to demonstrate its strengths

The timber used for the body of the Timber Wave is American red oak. Red oak grow abundantly in the American forest, making up around 30% of all the hardwood trees. Yet it has not traditionally been used a great deal in Europe.

AHEC is committed to the sustainable use of timber, and is currently carrying out an in-depth life-cycle analysis study. This will show the low environmental impact of American red oak, even taking transport issues into account. Timber is the most sustainable construction material, as not only does it come from a renewable resource, but it is the only structural material to actually absorb carbon dioxide while it is growing. This carbon dioxide remains 'locked up' for as long as the timber is in use. But evidently the most sustainable way to manage a forest is to make use of all the trees that are growing. That is why AHEC is eager to promote the use of red oak, and to encourage other designers to specify it, by showing how imaginatively it can be used and how durable it can be.

What exactly is American red oak? It is a number of closely related species, all abundant in the eastern part of the United States. The trees grow tall, so there are plenty of long wide boards available, with an even grain. The timber combines high strength with good workability, which means that it can be machined easily.

The characteristics of red oak can vary according to growing region. Some of the oak is so pale that it could be mistaken for white oak, while timber from other trees has an attractive pinkish hue. Eight AHEC members donated red oak for the Timber Wave, and there is an appealing variation in appearance.

When a timber is to be used structurally, it is important that its behaviour and strength are understood fully. Fortunately, in the case of American red oak the information exists. This is because, several years ago, a project by Hopkins Architects and Arup pioneered the structural use of American white oak in this country.

This project, Portcullis House, which opened in 2001, was such a success that after its completion AHEC commissioned Arup and the Building Research Establishment (BRE) to carry out structural testing of several other timbers, one of which was red oak. It was the existence of this data, written into a design code called Eurocode 5, that allowed Arup, the engineer of the Timber Wave, to calculate the size of the pieces that would be needed.

To improve durability for external use, the red oak was treated with a biocide stabilising oil from specialist company Osmose, that does not darken or discolour the timber. Field tests are currently under way on the long-term performance of the biocide oil but it seems that, with regular re-application and careful detailing, these timbers could stay outside for a considerable time without deterioration.

Development

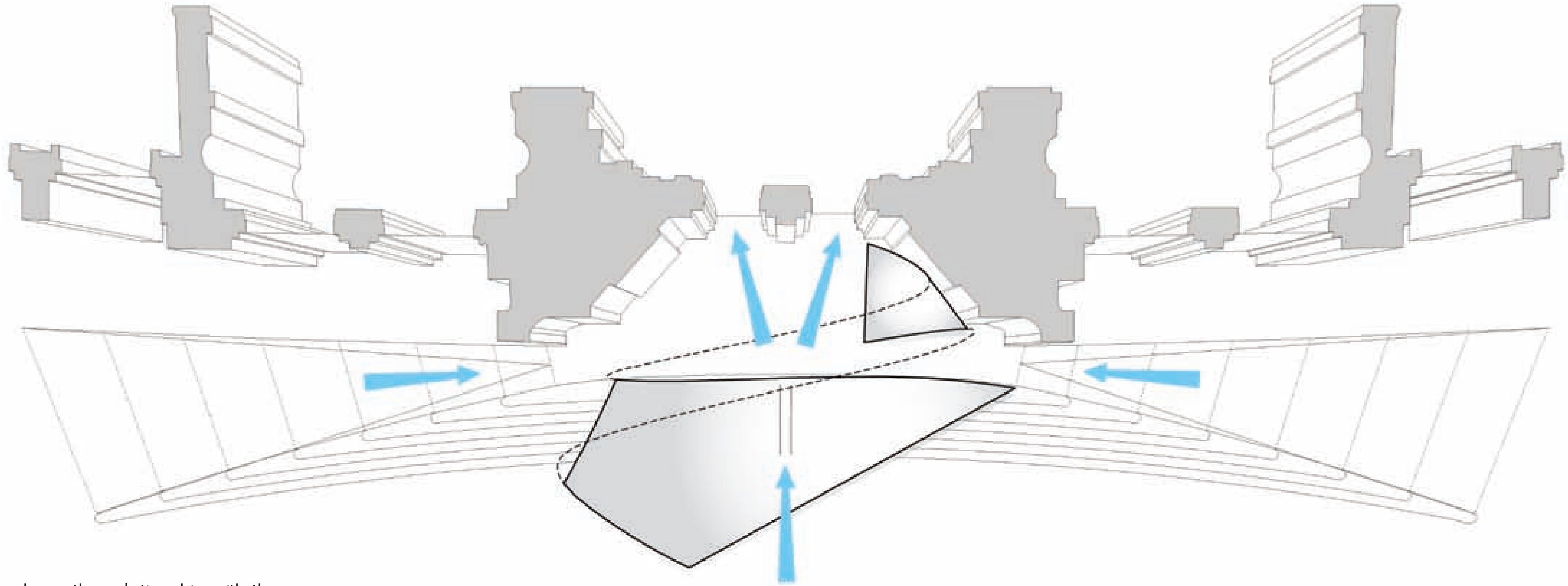
Establishing the right relationship with the museum entrance was vital to the early thinking

It is interesting to see how an architect responds when given an open-ended brief. In this case, it had a material (timber), a location (the Victoria and Albert Museum), an event (the London Design Festival) and a budget. What it did not have was a detailed functional programme in the way that an architect has when designing a building.

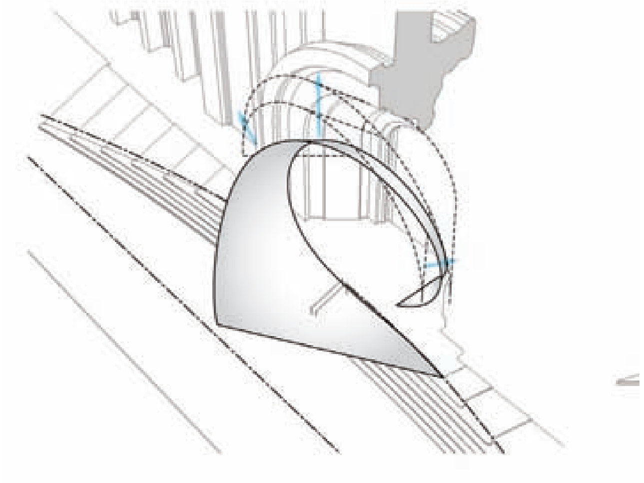
AL_A wanted to find a way of taking the Victoria and Albert Museum out onto the street to celebrate the London Design Festival residency at the museum and reflect the spirit of design and making.

The Victoria and Albert is a grade I-listed building, an important consideration in the design process. Permission was granted to build on the museum steps, enabling the designers to respond closely to the façade. The piece reflects the form and intricacy of the historic façade, sitting on top of the steps so that people entering the building walk both underneath and over the piece. The arch spirals outward onto the pavement, taking the museum out onto the street.

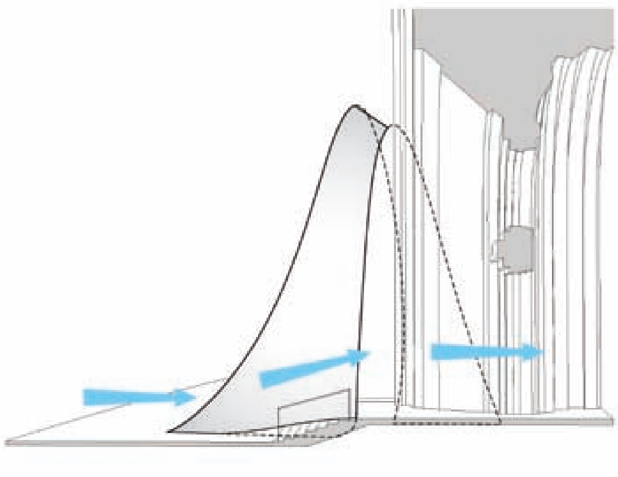
> “ The piece reflects the form and intricacy of the historic façade ”



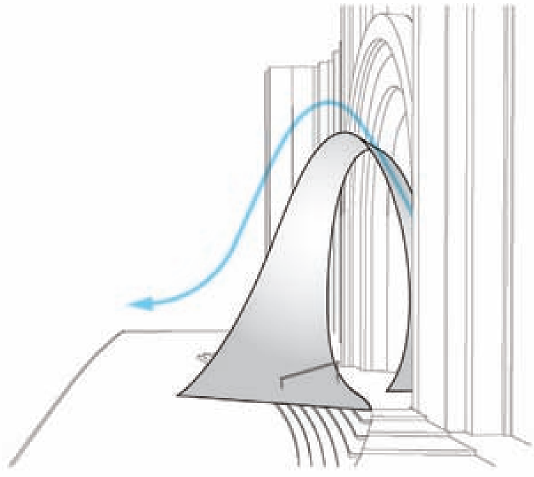
Plan shows the relationship with the museum



The form reflects the museum entrance



Visitors enter through the piece



The form spirals outward from the façade

Final form

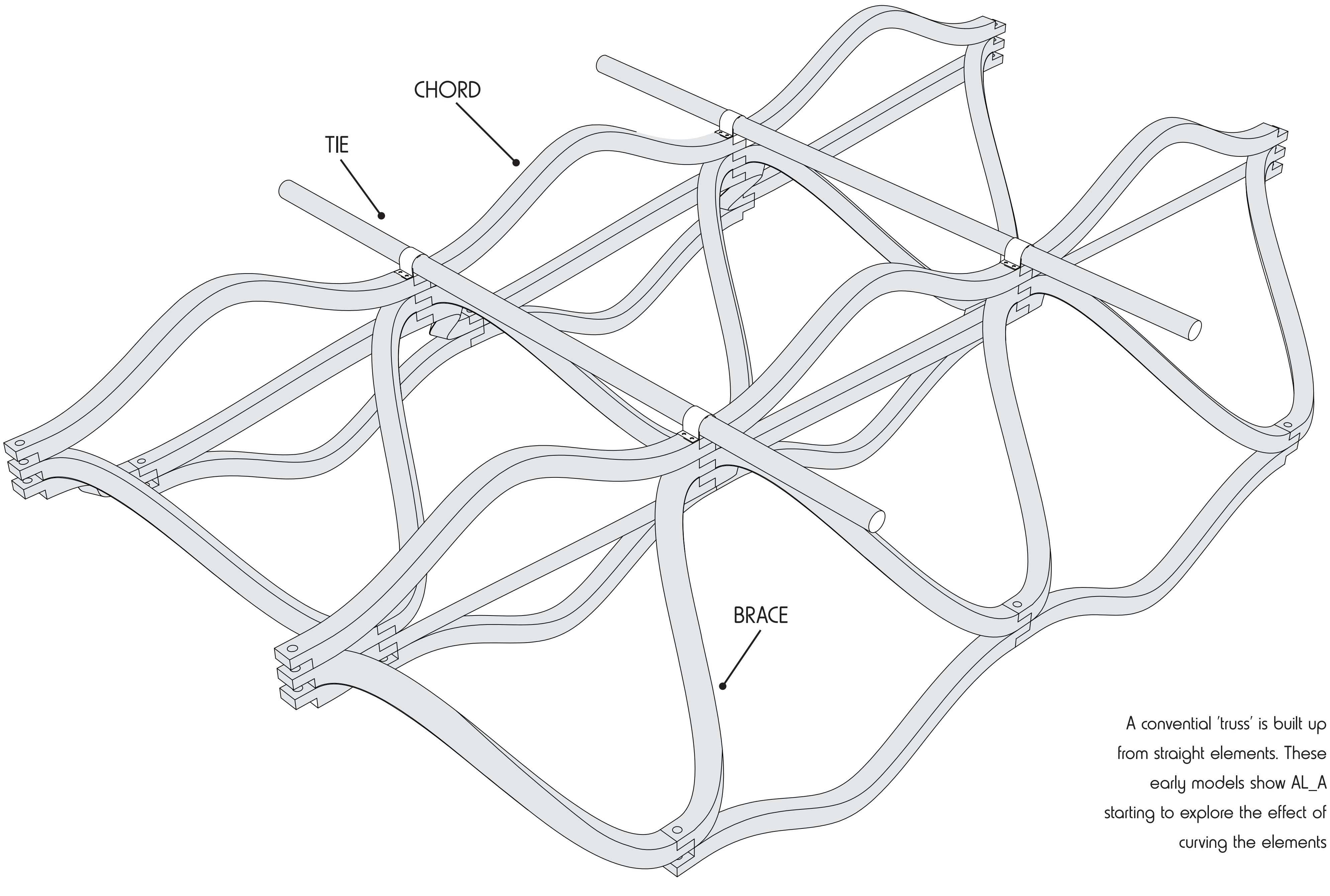
Collaboration between architect and engineer was a vital ingredient

When Arup discussed with the architect the efficiency of the 'truss' form, a simple triangluated structure built up from chords and braces as shown opposite, the result was the sinuous curved form in which all the elements are curved. As a result, the visitor reads it as if all the elements are performing the same function. In fact, there are six outer chords and five inner chords, joined with braces. In addition there are some straight ties, connecting the outer chords.

Once the structural principle had been determined, there were two great challenges: coming up with the detail of the form, and working out how the connections could work.

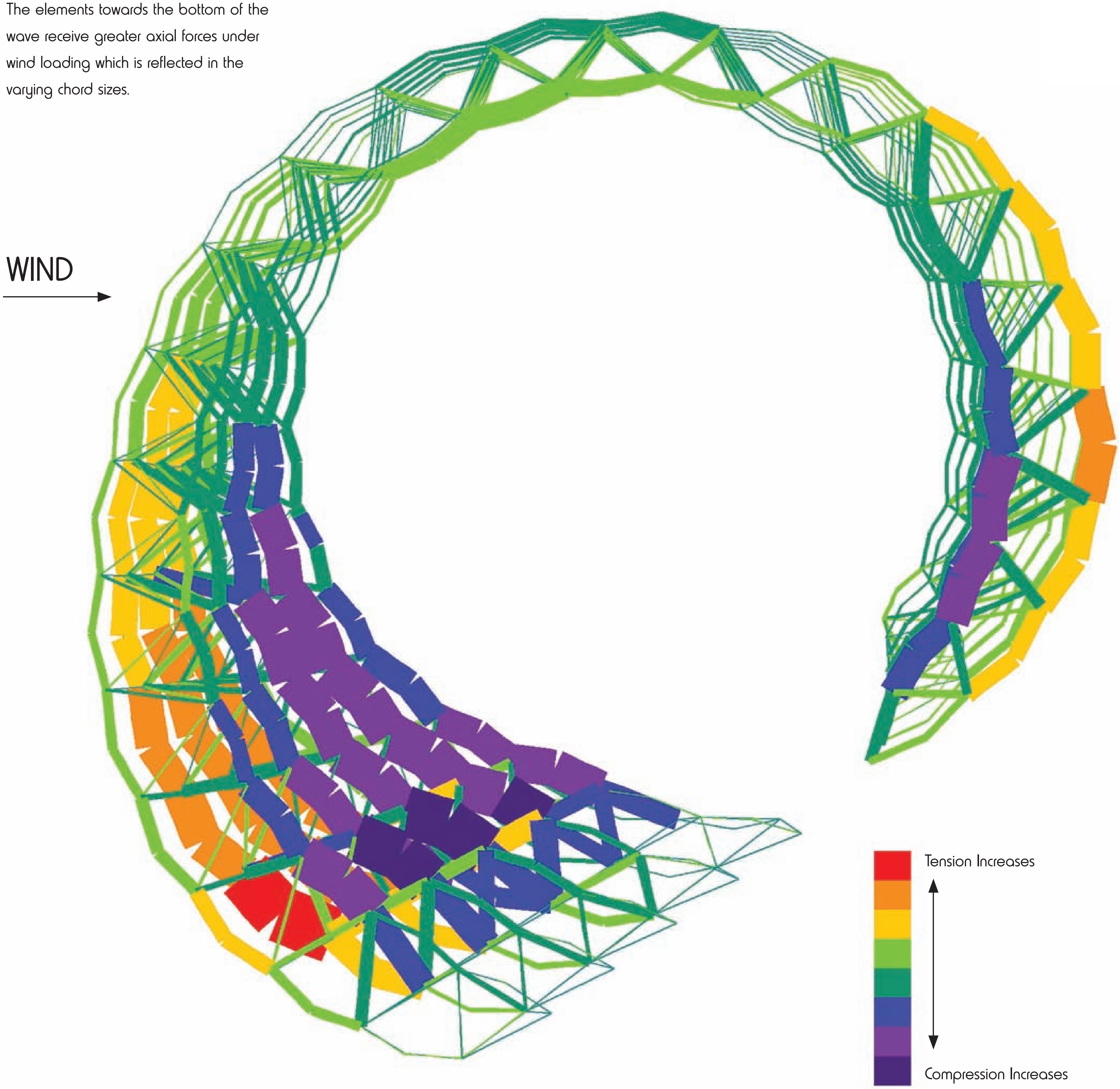
The form is entirely three dimensional, and in developing it at an early stage, AL_A did not use drawings but, as it often does on its projects, simple physical models. These are very different from the beautiful finished models that an architect may produce at a later stage, instead being very much a working tool.

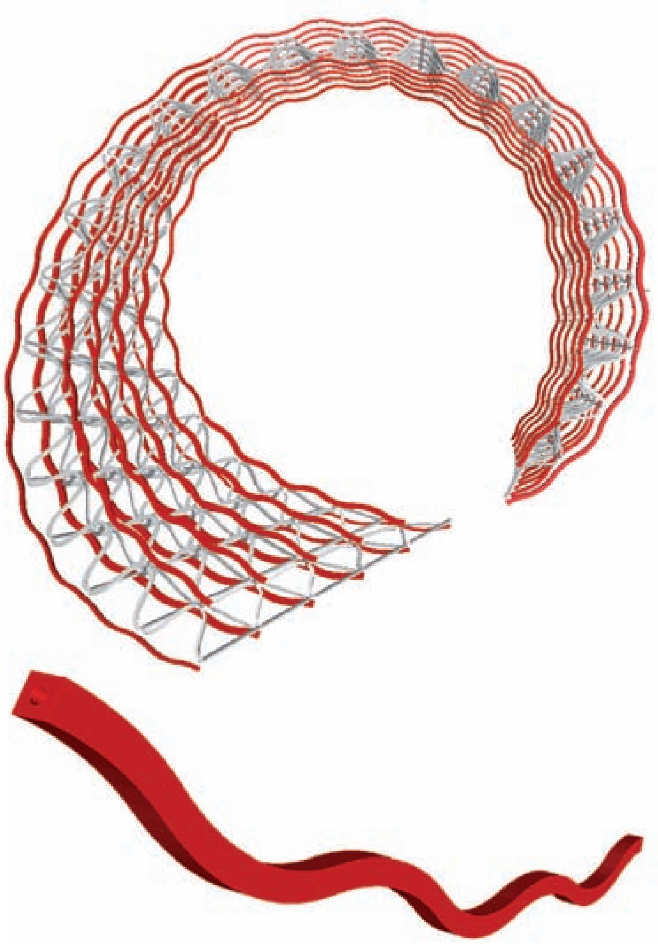
Then, when it wanted to refine the form, the architect used some clever software called Grasshopper. This works in conjunction with Rhino, a drawing package that many architects use. Grasshopper can play with a lot of variables. It is software that users program themselves, to describe the relationship between the elements in the



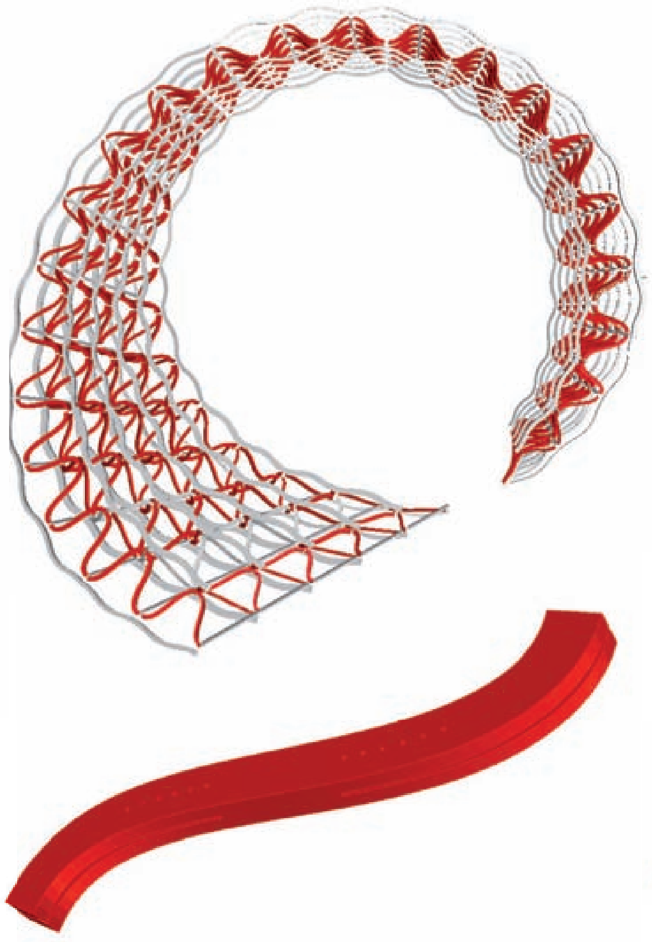
A conventiial 'truss' is built up from straight elements. These early models show AL_A starting to explore the effect of curving the elements

The elements towards the bottom of the wave receive greater axial forces under wind loading which is reflected in the varying chord sizes.

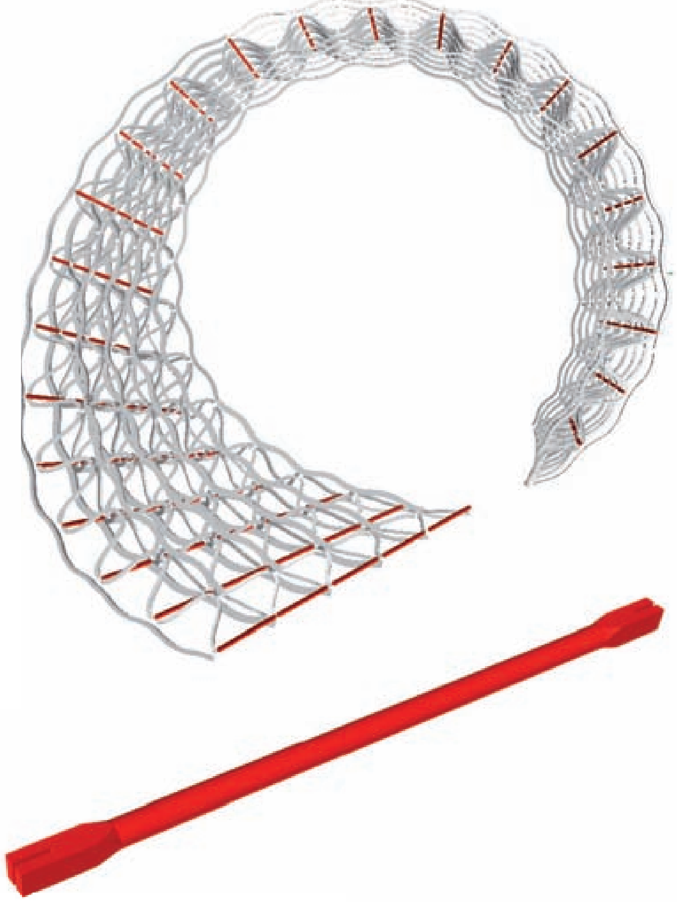




The 88 curved chord elements were built up from thin layers of glued laminated timber. There are 14 types of chord elements with a length range of 2,600mm to 4,600mm



The 460 curved braces were cut out from flat pieces of timber. There are 45 types of braces with a length range of 500mm to 1,400mm



The 96 ties, needed to provide additional stability, are straight with square ends and round central sections. Ties have a length range of 150mm to 1,600mm

design, their dimensions and also other variables such as cost. Once you have set up these relationships, you can change a single element – for example, the length – and see the effect on the overall design. This approach, for which the correct descriptive term is parametric, allows the designer to be far more imaginative, since they can rapidly see the effect of the changes that they make to the design. They also used this process to standardise the number of components.

There was also a trade off between elements of the design and the cost. For example, the tighter that the curves were in the components, the thinner the laminates would have to be, since you can only achieve a tight curve in a really thin piece of timber. Each laminate had to be cut to size, have glue applied, and then be put together with its fellows – a time consuming process and one with a considerable degree of waste. AHEC members had donated one container of American red oak, so there was a finite amount of material to work with – and a finite amount of time in which to complete the structure.

Even with the compromises that have been made, the laminates are very thin. Typically, in glulam structures, they are 35-40mm thick, but on the Timber Wave, with curves of a radius as low as 1m, they are only 7mm thick.

Making connections

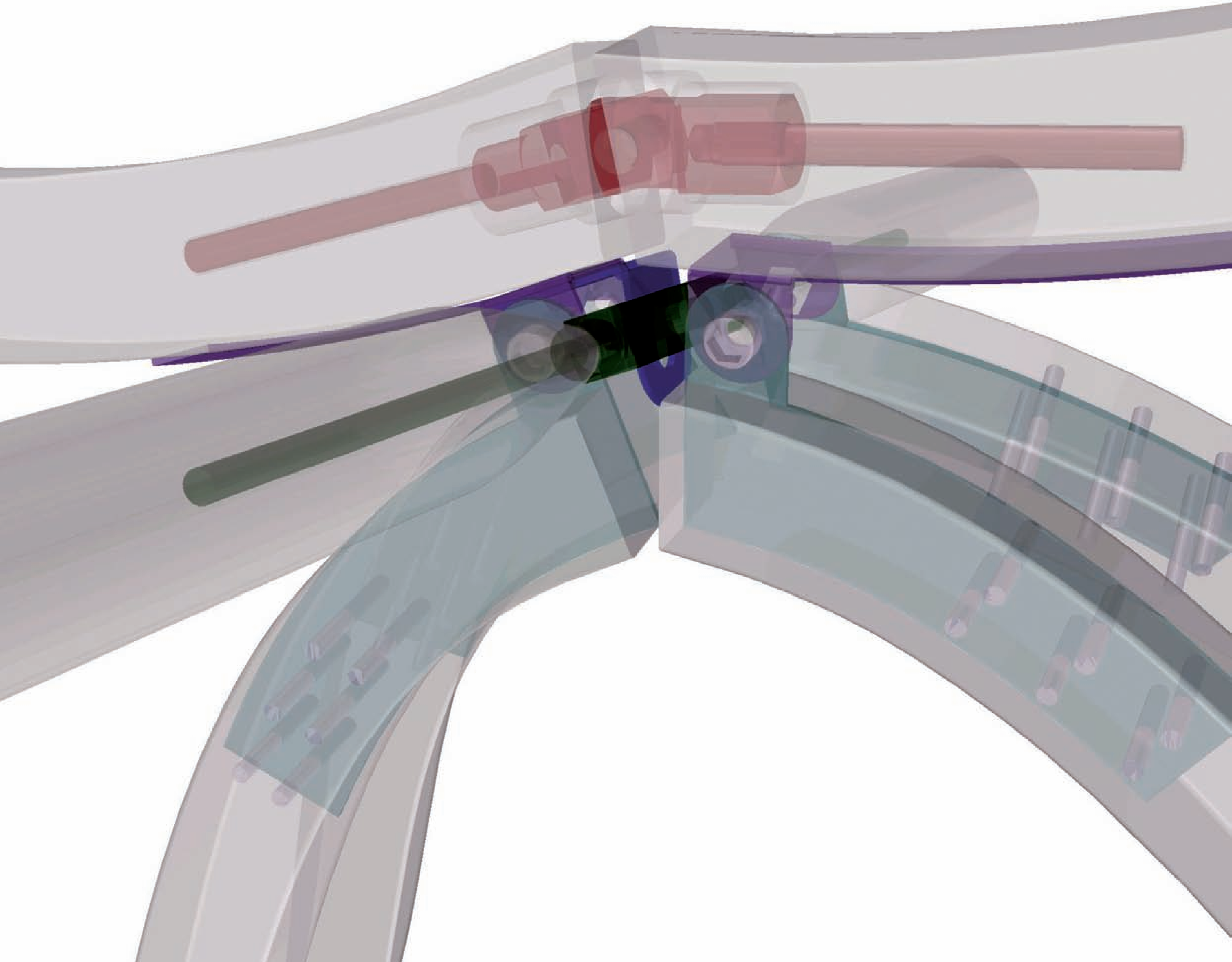
Designing the joints was a challenging exercise in three-dimensional geometry

Getting the connections right was vital to make the very complex joints work. At a typical joint, there are two chord sections joining end to end, with four curved braces. If these are outer chords they also have two ties, joining them to their neighbours. Arup designed all the connections in stainless steel, because the naturally occurring tannins in the oak would react with mild steel and stain the oak. The connections needed to be as discreet as possible, since the overall effect should be that one sees as much timber as possible, and as little steel.

The braces have been 'flitched' with stainless steel plates at their ends. This means that thin plates of stainless steel have been inserted into the components, and fixed to them, so that they can take up some of the stress, as well as forming a method of connection. Bolts are fitted through 'lugs' at the end of them. The plates are standard, but the angle of the lugs is different for every joint. The chords have steel rods inserted into them that are connected with a fixing called a clevis.

The structure had to be designed not only to bear its own weight, and the considerable loads that it imposes in tension and compression, but also to cope with external forces, in particular wind loads. With such a complex design, however good the calculations, one has to be certain that the elements will behave in practice as one has calculated. There was therefore a considerable amount of testing carried out at Cowley Timberwork at the start of the manufacturing process.

Diagram showing connections, including flitch plates and clevis joint



Production

Once Cowley Timberwork had been appointed the contractor to make the Timber Wave, some further adjustments were made. One was to do with the amount of laminated timber that was used. The great advantage of laminated timber is that the grain all lies in the right direction. The fibres run in the direction of the wood, making it as strong as possible. The disadvantage, as described earlier, is that making the laminated pieces, especially with the very thin laminates needed here, is time consuming. So a compromise was made. The chords are all made from curved laminated timber, but the braces have been cut from flat pieces of timber. All the braces are 60mm deep, made up from three 20mm lamellae. They were arranged so that the main part of each component had the grain running in the right direction but evidently, because they are curved, this could not be true for the complete piece. Where there was any potential weakness, this was taken up by flitching with a longer piece of steel. Similarly, the ties, which are straight, are made up from three 20mm lamellae, to measure $60mm^2$ at the ends. At their centres, they have been turned to create a circular profile.

The other adjustment was also to do with the laminated timber. Making the moulds on which the timber is bent is another time-consuming process. So the elements were designed as a ‘family of curves’ with the flattest made first, and then the moulds cut away a little to create a greater curve. In this way Cowley Timberwork was able to make do with using only 12 moulds, reshaping each one so that it could create a total of 24 different curves.

Manu facture

Making the Timber Wave was a skilled and time-consuming process

Cowley Timberwork is a company that specialises in unusual projects with a large number of one-off pieces. It has worked on some of the most prestigious and challenging timber projects in the country. Occupying a number of buildings on a site outside Lincoln that it shares with a car breaker, its superficially low-key operation actually houses a range of highly specialist equipment, run by a skilled workforce. The simple buildings have enough space in them to house mock-ups and experimental assemblies. Work on the Timber Wave took place in a number of different buildings.

Because the American red oak was donated by a number of different suppliers, it came in a range of lengths and widths, as well as showing considerable variation in colour. It had all been graded for use in joinery but in addition there was a visual inspection, taking out any weaker elements with large knots or high slope of grain.

Images: Johnny Boylan

> “The simple buildings have enough space in them to house mock-ups and experimental assemblies”

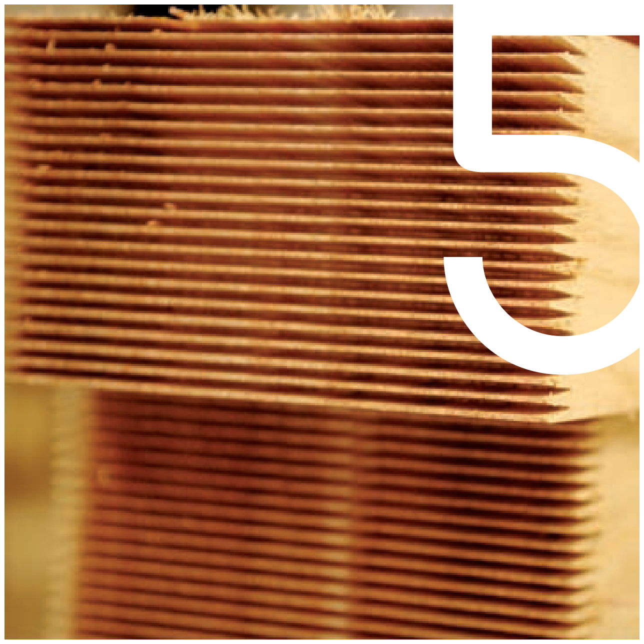
Billinghay Sawmill trimmed and planed the boards, and cut the 7mm and 20mm lamellae. These had to be planed again to the tightest degree of accuracy.

At Cowley Timberwork, visual inspection further improved the quality. In addition to cutting out any severe looking knots, where there were some slightly less high quality lamellae, it placed these in the centre of the timber ‘sandwiches’, where the stresses were less. The very best pieces were reserved for the outer parts of the sandwich, where they were both visible and having to do the most work. Tests showed that the line of the grain (a kind of invisible texture) ran almost perfectly straight along the lamellae.

The next stage was to spread the laminations with glue and put them together into the requisite depth of sandwich.

While the glue was still wet, the glued timbers were placed in a mould in a press, where they were bent to shape. From there they were transferred to a larger clamp, where they were held at an elevated temperature, until the glue had set. Typically this happened overnight.

Once the elements were removed from the clamps, they were trimmed and sanded, achieving an elegant, furniture-like finish. The darker-coloured elements had already been dipped into the tank of biocide oil.



Next, pairs of curved elements were finger-jointed into longer lengths. Finger jointing is a process where an accurate zigzag surface is cut, so that when two elements are joined together it is with a very large surface area, so the bond is very strong.

The dimensions of the chords range from 80 x 140mm at the bottom of the structure, to 60 x 60mm at the top.

The braces were cut out using a CNC machine, and then went through a similar process of preparation, as did the ties.

> “The timber elements were found to perform better than expected”

There are a total of 258 nodes. Every element was numbered with the number of its node at which it connected. Without this system, putting the finished object together would have been like the world's most challenging jigsaw puzzle. A certain amount of trial assembly took place during the manufacturing process, and then the components were assembled into the large elements that were taken to the site for final erection.

When indicative testing was carried out at the works, the timber elements were found to perform better than expected – a tribute both to the quality of material that had been supplied and to the care and skill that went into making the elements.

Installation

With such an ambitious project, installation was always going to be a challenge

> “The sections were carefully manoeuvred into place using block and tackle”

One could almost think of the whole process of manufacture as a rehearsal for the final stage – the installation on site. Cowley Timberwork preassembled six large pieces in the factory and delivered them to site. Each large piece had to be connected to the next with pin-point accuracy. This was a hugely complex process and Skanska's temporary works team offered invaluable support.

The first preassembled piece to go in place was the bottom piece on the museum landing. This was fixed to the 'foundation' – a large steel plate weighed down by massive steel counterweights. A large scaffold then had to be built to support subsequent pieces that were lifted by a crane and carefully manoeuvred into place using block and tackle and bolted together.

Once all the pieces were connected, the Timber Wave was released slowly from the scaffold, allowing it to become self-supporting before the scaffolding and hoarding were removed, lights were fixed and the Wave was in place.

Dark art of lighting

The lighting design emphasized the structure's curves and organic nature

With the festival in mid-September, there were almost as many hours of dark as of daylight and it was important the Timber Wave should be a stunning beacon at all times. Using lights supplied by iGuzzini, SEAM created a scheme strengthening the relationship between the arch and the entrance by highlighting the warm tones of the latticework and geometry of the arch, while allowing the light to pass through and project inherent patterns onto the facade.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The American Hardwood Export Council (AHEC) runs a worldwide campaign to promote the use of American hardwoods. AHEC concentrates on providing architects, specifiers, designers and end-users with technical information on the range of species and products, and sources for supply of American hardwoods.

AHEC's affiliation with projects such as AL_A's Timber Wave help to demonstrate the versatility, aesthetic appeal and structural potential of U.S. hardwood species, providing valuable inspiration, knowledge and confidence to designers, architects and engineers globally.

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