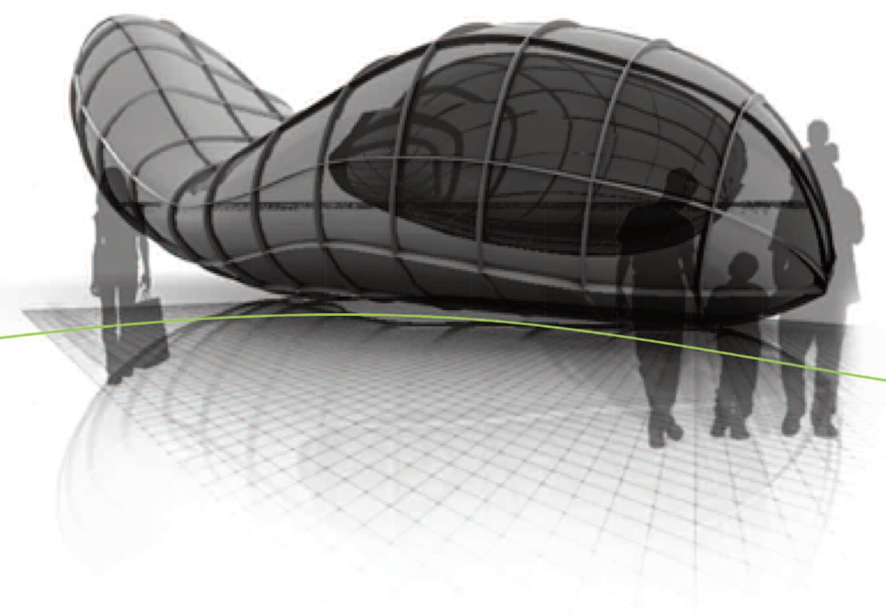
FLUID.STRUCTURES

ENGINEERS AND TECHNICAL DESIGNERS

free form biomorphic structures



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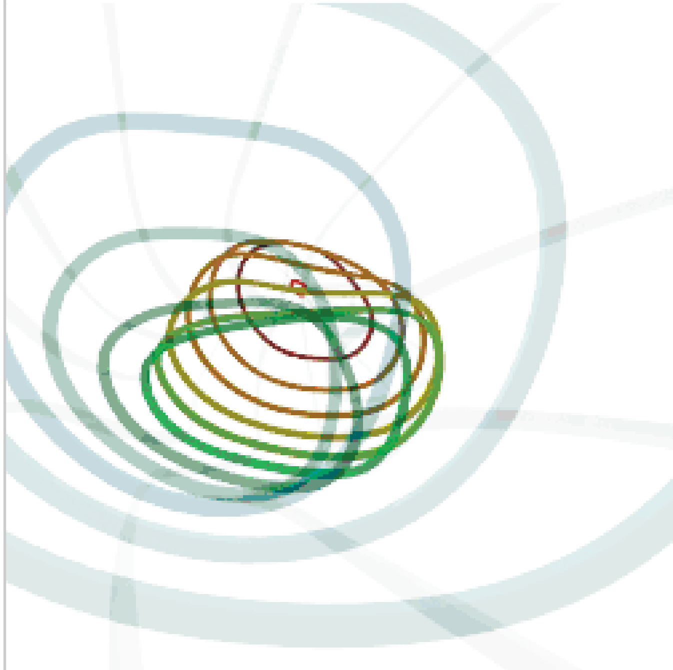


introduction [1.0]

Fluid Structures are a practice of structural engineers working in conjunction with architects, designers and artists. The practice was established in London in 1999 and has grown steadily since its inception. The project types range enormously and the office has provided input on projects ranging from the design of a single chair to multi million pound commercial developments.

The practice was founded with the idea that structural engineering is not simply a subservient discipline that resolves technical issues. We believe that it is a unique discipline where the science of materials and the use of mathematics in analysis can be blended in the realisation of structural forms.

Modern technology and computational advancements have allowed us to leave behind the traditional approach of post and beam construction and allow us to consider new forms. We are keen to investigate new ways of putting things together.

A wide range of building forms have begun to emerge in the 21st Century. Amongst the many influences, the diversity and sophistication of the natural world is a constant source of inspiration.

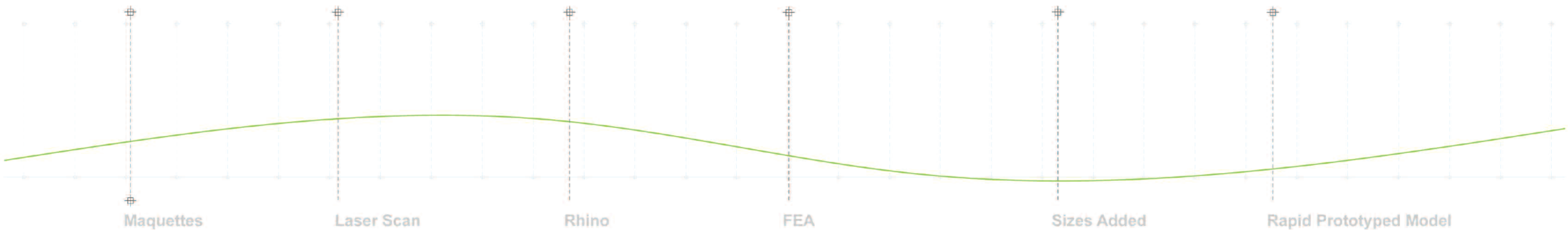
As an engineering practice we are keen to develop a closer understanding of the natural world, its biology and its ecological systems.

We want to avoid interpretations that are two dimensional images or biological cartoons that simply mimic pretty shapes and fluid outlines.

We structural engineers are perhaps best equipped to explore the generation of biomorphic forms and investigate their symmetries.

"We need to identify a pathway that brings into harmony the spatial and structural considerations and allows them to cross pollinate and create new forms."

1. Tony Campbell (Photographer) Ice on Leaf



introduction continued [1.1]

This research website considers the process that can be used in the development to construction of a freeform (biomorphic) maquette.

The maquette was constructed in polystyrene and was made by one of our staff (Grace Simmons) over several lunchtimes.

A decision was made early on to work in this way as we wanted to begin with a physical model that we could touch and feel rather than a digital model that would not have the same sensory value.

The idea was to create a form that was independent of scale and could be the first draft of a sofa for a lounge or the outline of a new gallery building.

The maquette underwent a number of processes including laser scanning, surface modeling, finite element analysis and rapid prototyping. The purpose was to explore these techniques, their crossovers and establish a pathway for the delivery of this type of form.

We hope that you will find our research of interest and if you have any queries or would like to collaborate on a project please do not hesitate to contact the office.

David Crookes Fluid Structures 2006

1

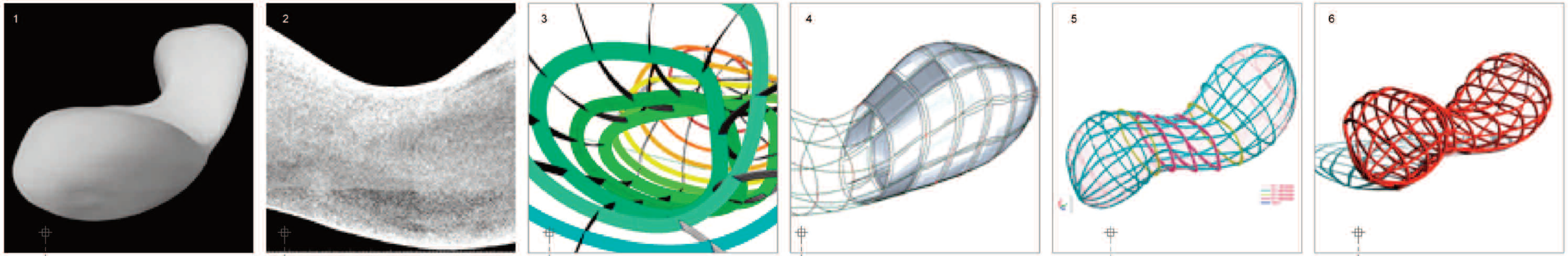
2

3

1. Eva Hild (Artist) Stoneware ~ 2003
2. Bill Brandt (Photographer) Nudes
3. Hans (Jean) Arp (Artist) Torso-Garbe ~ 1958

process [2.0]

Time line illustrating the stages of the pathway



1 Maquettes
A physical model (Maquette) is prepared in polystyrene and plaster of Paris.

2 Laser Scan
The Maquette is laser scanned to create an IGES file.

3 Rhino
The file is manipulated in Rhino (3d NURBS modeling software) to create an exo skeleton structural frame..

4 FEA
The exo skeleton is then analysed and sized in robot, a finite analysis program.

5 Sizes Added
The rings and contours have sizes attributed and are checked for stress.

6 Rapid Model Prototype
A rapid prototype is then created by exporting a .STL file of the Maquette.

Making the form/maquette [2.1]

The form to be developed was sketched out on polystyrene foam and trimmed to shape with a saw blade which easily cuts through the polystyrene material. The form is defined by using a hot cutting wire and then refined with a scalpel blade.

After this process, the entire form is covered with Plaster of Paris or an all purpose patching plaster. This is applied in two separate coats at intervals of 1-2 hours to ensure that it is covered as smoothly as possible and that enough layers of Plaster of Paris has been applied. It is recommended that it is left overnight to dry under normal conditions. When the model is completely dried, it is refined further by sanding it as smoothly as possible to remove all bumps. It is then ready for laser scanning.

The surface is not sealed as this can affect the scanning process and is cautioned against by the scanning company.

1. First application of plaster.
2. Preliminary sanded form.
3. Polished Plaster Maquette.

laser scaning [2.2]

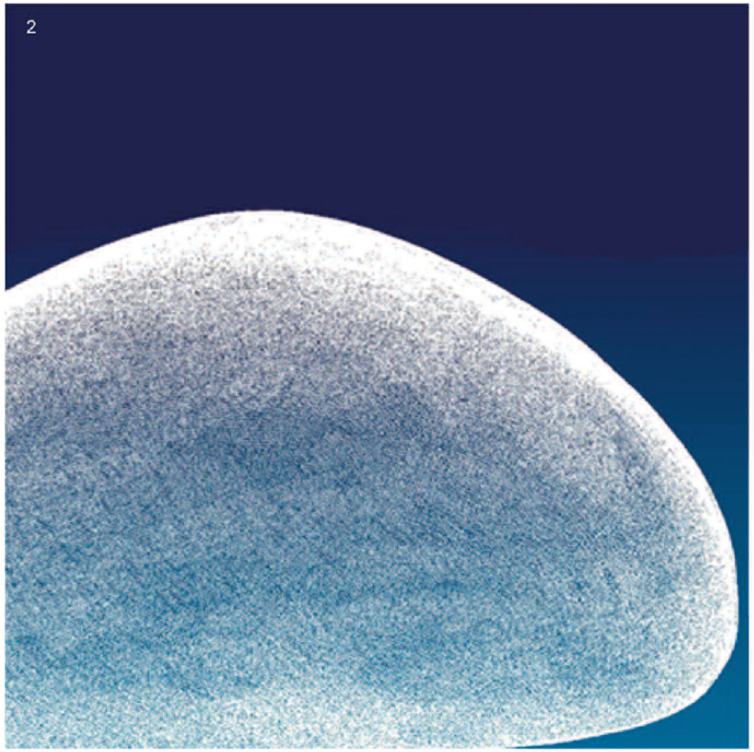
1. Spraying the form
Before the form is laser scanned, it is sprayed with a flaw finder spray which makes it non-reflective and enables the scanner to gather accurate data from the form.

2. Laser Scanning
The 3D laser scanning of the model generates point cloud data that accurately forms a 3D representation of the model electronically. The laser is able to capture about one thousand points per second and depending on the size of the model, the total number of point cloud data can range from hundreds of thousands of points to millions of points.

This is the staring point of our CAD design and subsequently, the Finite Element Analysis.
The scan method that is employed to reproduce the object depends highly on the scale of the model. In this case a Faro Laser Scanner was used.

Point Cloud
Once the scanned data has been generated, the 3D point cloud data can then be exported into Geomagic Studio (a reverse engineering software) where it is compared with the original physical model and Initial Graphic Exchange Software (IGES) data is generated.

3. Rhino
The data is then imported into Rhino (NURBS surface modeling software.) The Rhino software allows the *.iges data to be refined (very important) and allows the establishment of primary structural curves and nodes. Once it has been imported the file has to be oriented into the desired position and size by rotation and/or scaling.



contours in rhino [2.3]

Within Rhino, contour curves are created through the form. This is done by selecting surfaces, polysurfaces, and meshes for contour line creation.

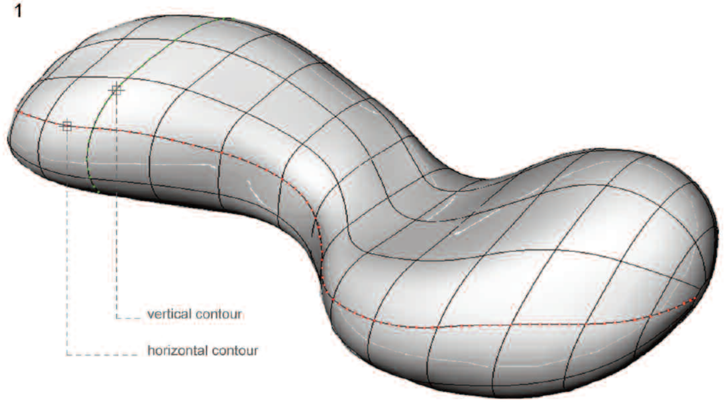
The distances between the contours must be specified and the contour curves are created where the contour planes intersect the surface and poly surfaces.

The lofted contour curves have a surface mesh as shown which must be deleted before exporting into the Finite Element Analysis software.

This eliminates the problem of working with thousands of nodes and elements in the FEA package. The deleted leaves polylines which can then be exported as a *.dxf file to the FEA package.

At this stage the scale of the original maquette was changed so that the project better mimicked the design of a habitable space/building. The distances between the vertical contours was specified such that the overall length of the free form was approximately 40 meters.

1



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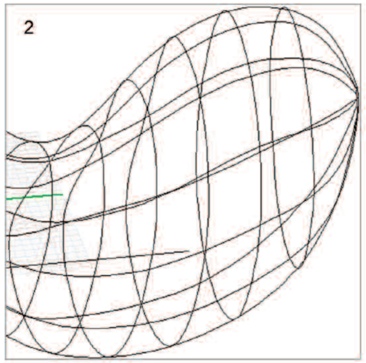

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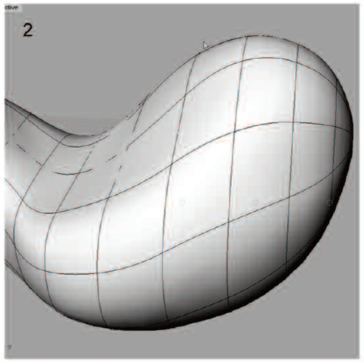

1. Model with vertical and horizontal contours.
2. A contoured model with and without a surface.

FEA analysis [2.4]

Within Rhino, contour curves are created through the form. This is done by selecting surfaces, polysurfaces, and meshes for contour line creation.

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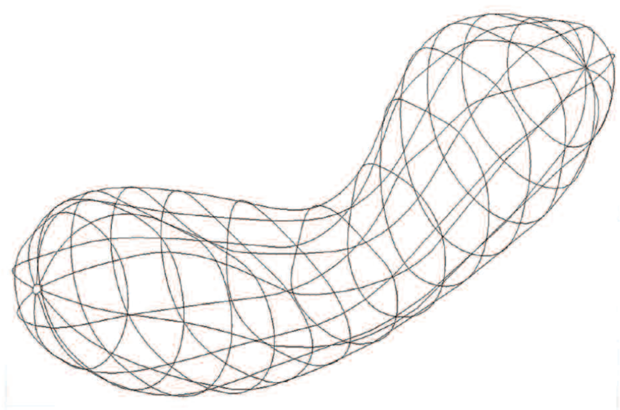
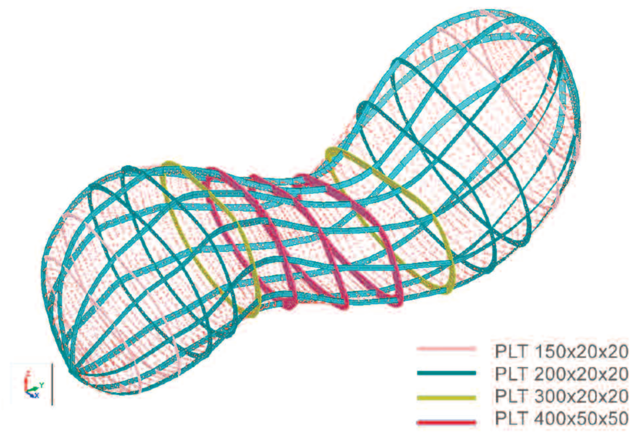


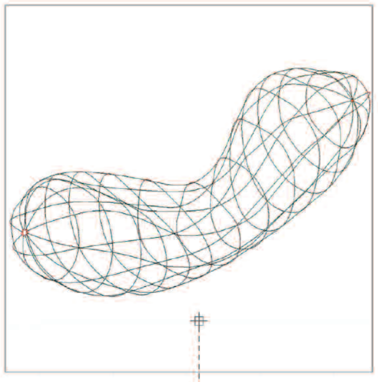


Input: polylines are imported as a .dxf into Robot

Output: colour guide to differentsections attributed to bars

FEA analysis 1 [2.41]

1



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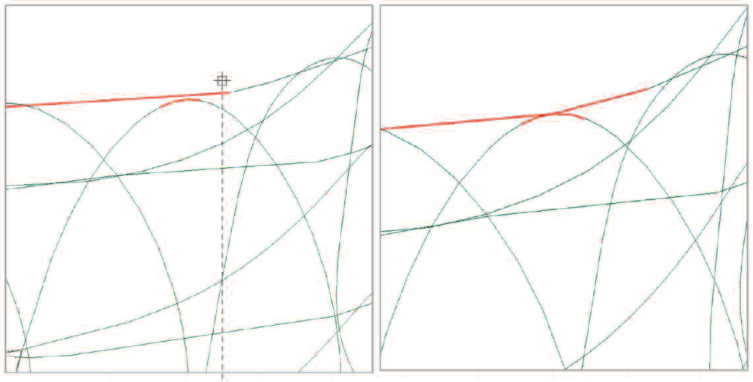

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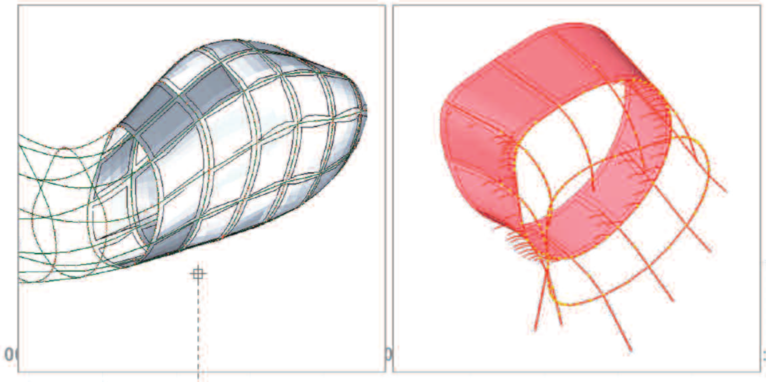


1. Importing .DXF

The polyines are imported as a .DXF file into Robot Millennium, a Finite Element Analysis software where the component parts, ribs and spars are designed based on stress analysis. It is important to scale the model at this stage to the desired size before any analysis is carried out.

2. Modifying the .DXF

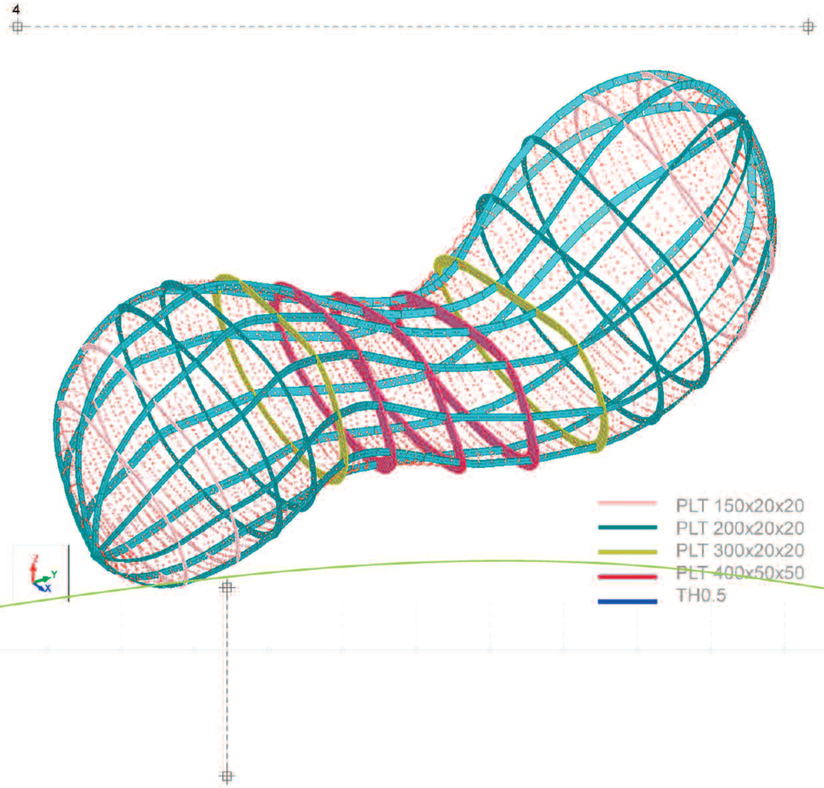
A common problem that arises when the .dxf file is imported into Robot is that the polylines are tessellated into line segments that are staggered so some of them do not touch at intersections to form a common node. To solve this each section with an intersection is examined and fixed separately as shown in the two images above.

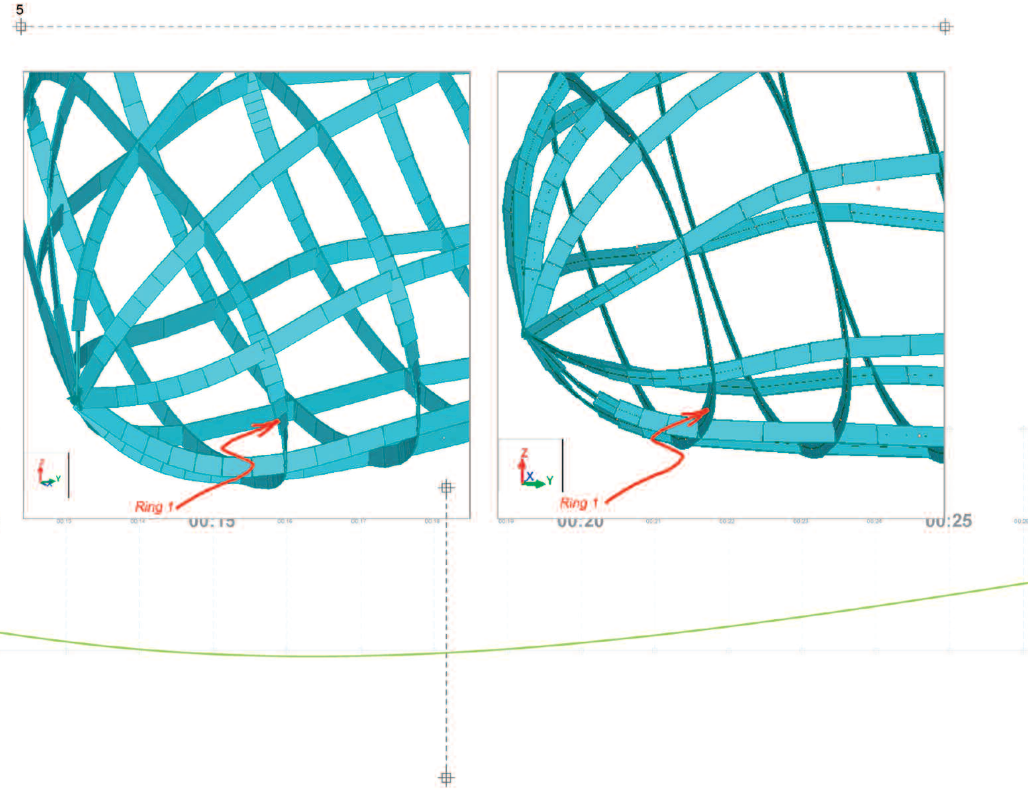
3. Defining Panels

Panels / cladding are the defined within the structure.
It is recommended that the panels are put on section by section to enable accurate selection of the internal point of the panel / opening.

The main reason for putting panels/cladding on is to enable us to generate a finite element mesh on which loads can be put and structural analysis can be performed.

FEA analysis 2 [2.42]





4. Choosing Sections

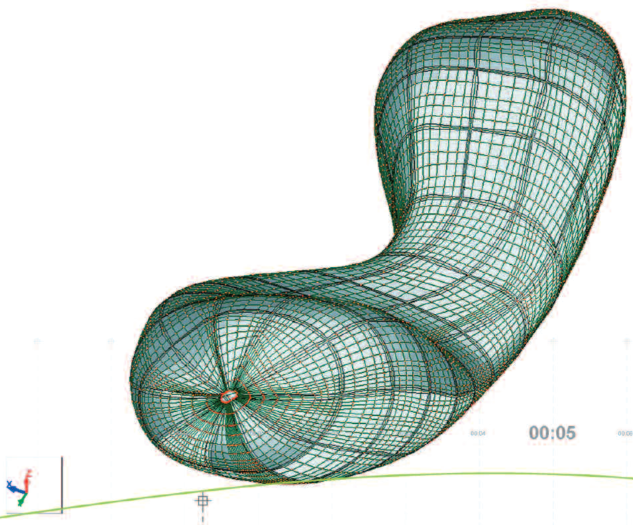
From the Geometry menu within robot select "Properties" and then "Sections" or click on the Bar sections icon on the sections toolbar. Click on new to define the properties of a new section or choose from the default list of sections.

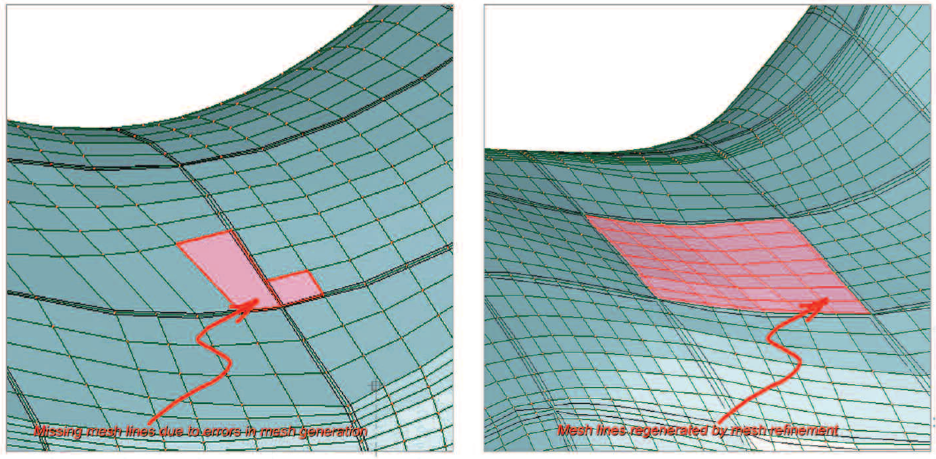
5. Correcting Section Positions/Orientation.

A problem that arises when the sections are assigned to the bars/elements is that they "twist" at curves and do not face the desired plane. This must be corrected by examining the model and altering the orientation of the elements that are twisted.

The diagrams above show Rings 1 of the model before and after correction by Gamma angle rotation (It is difficult to get the same snap shot as the model rotates to assume the correct orientation).

FEA analysis 3 [2.43]





6. Mesh Generation.

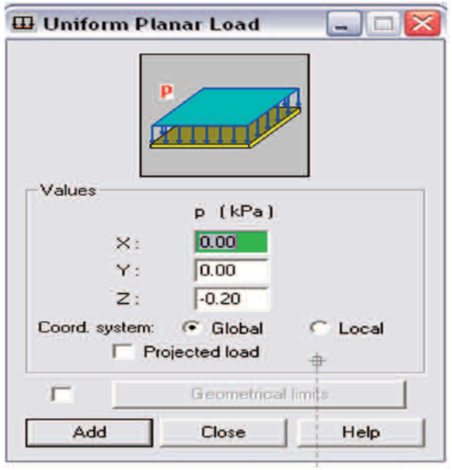
At this stage the Finite Element (FE) mesh is generated to be carried out. This takes a few minutes to generate and upon completion a Structure Verification dialogue box pops up to confirm that there are no errors or warnings with the generated mash and alerts you if there are any.

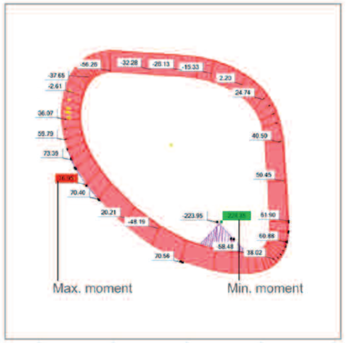
7. Correcting Errors Within the Mesh.

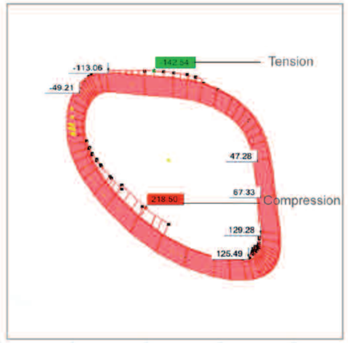
A problem that arises when the sections are assigned to the bars/elements is that they "twist" at curves and do not face the desired plane. This must be corrected by examining the model and altering the orientation of the elements that are twisted.

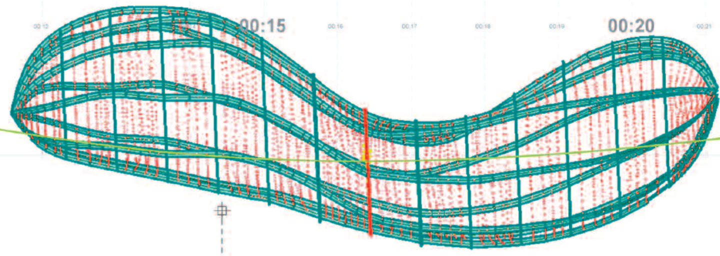
When errors occur, the Structure Verification dialogue box displays the type of error (normally, incoherent mesh on the edges), the number of errors and the number of warnings. These must be corrected using the mesh refinement command.

FEA analysis 4 [2.44]









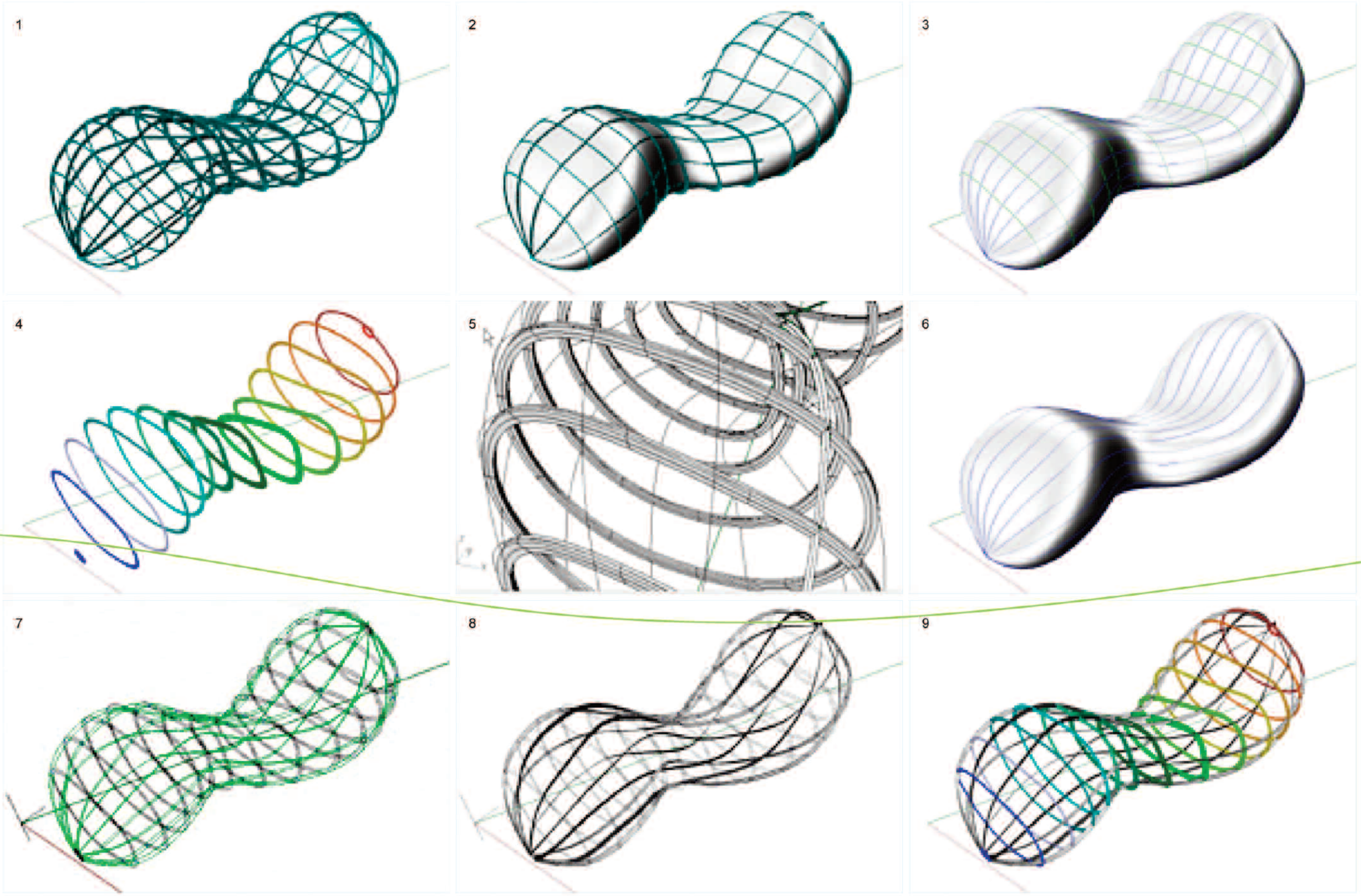
8. Applying the Loads & Supports
Different type of loads are put onto the model after the mesh has been generated. In addition the support conditions are identified.

9. Forces & Moments
When the analysis is complete the software allows you to examine each of the members and provides output results regarding displacements moments and stresses. This output is used to confirm the member sizes.

rapid prototyping [2.5]

Rapid Prototyping requires a model that only contains closed 'solids' that is elements with a clear 'inside and 'outside'. For example eight square surfaces can form a solid cube. when the model is imported back to Rhino from the analysis package, it consists of a number of disjointed cubes that intersect one another. For successful rapid prototyping these surfaces need re-connecting. The easier ones to correct are the planar cross-sections (rings).

1. A construction plane is created.
2. The model is aligned with the plane.
3. The model with the original UV curves is now ready to be offset.
4. The original model is lofted and the rings are colour coded for easy identification.
5. Each lofted surface is then extruded and capped.
6. The wireframe is then extracted from the model.
7. The longitudinal curves are then offset.
8. The longitudinal elements have been 'normalised' to the surface of the model.
9. The final continuous 'solid elements are now ready for prototyping.



rapid prototyping 1 [2.51]

FDM vs' SLA Technique

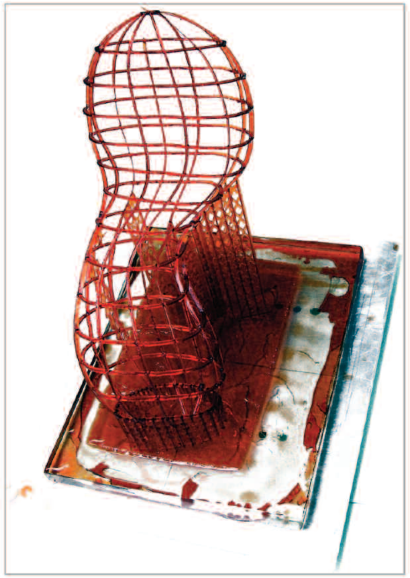
Two different techniques of prototyping were considered in the manufacture of the structure to achieve the best results; Fused Deposition Modelling (FDM) technique and the Stereolithography Apparatus (SLA) technique.

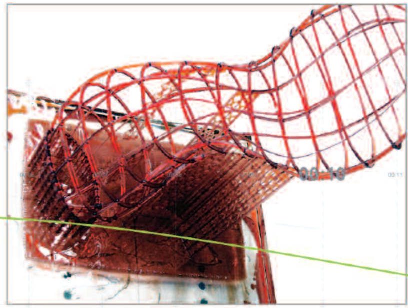
FDM Technique

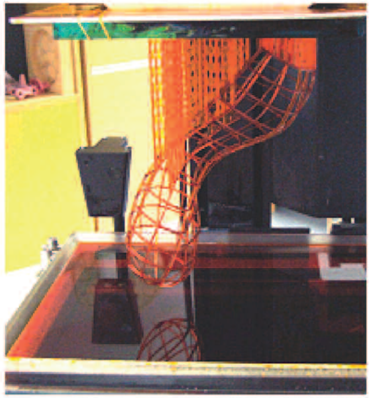
The main problem with the FDM technique was the difficulty experienced in generating the support model.

SLA Technique

Thus the SLA technique was used. In order to do this the size of the elements had to be changed to 1mm. This was because of the minimum thickness that can be successfully manufactured by the SLA machine is 0.5mm and it was deemed wise to have some comfort on this minimum dimension.







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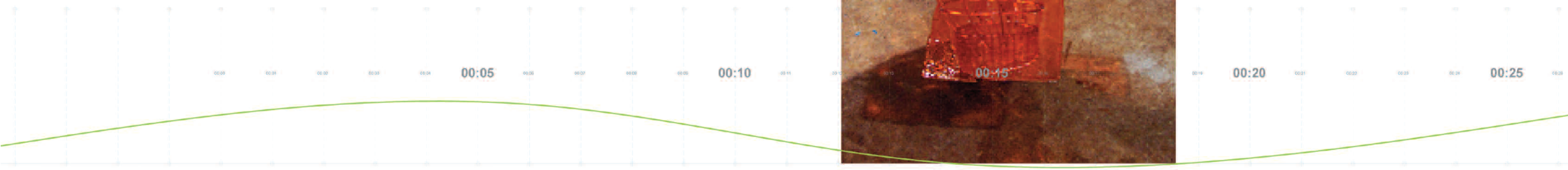
2

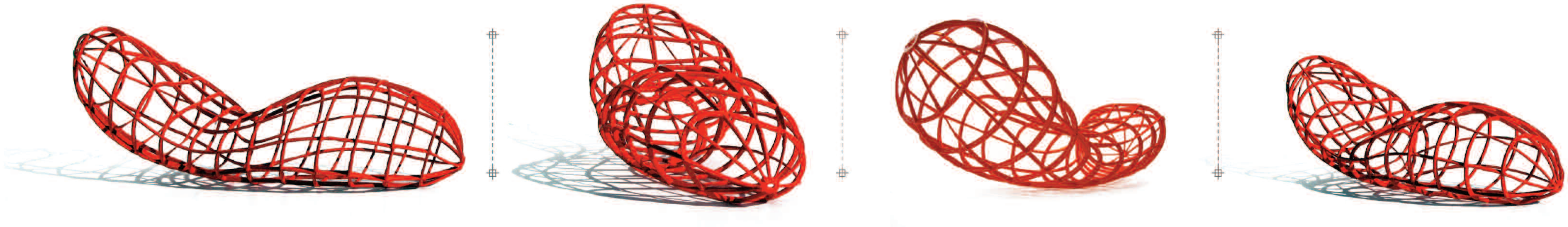
1 In the SLA technique the system creates a platform from which the 3D model must be oriented and positioned. The physical part is built on a base platform of a glass plate. This corresponds to the digital representation in the software and is referred to as the build bed.

2 Specific areas of the model require physical support during the build process.
The model is built by a repeat process of the glass bed dipping into liquid resin then extruding vertically for the resin layer to be cured by ultra violet laser light. Material supports are required to hold the model to the platform bed and to physically support and hold the structure during vertical build.

3.Figures 1 and 2 illustrate the SLA prototype model upon completion of the manufacturing process. With the model part having been grown layer by layer in the vat of liquid resin with the completed prototype model mounted upon the material support structure.

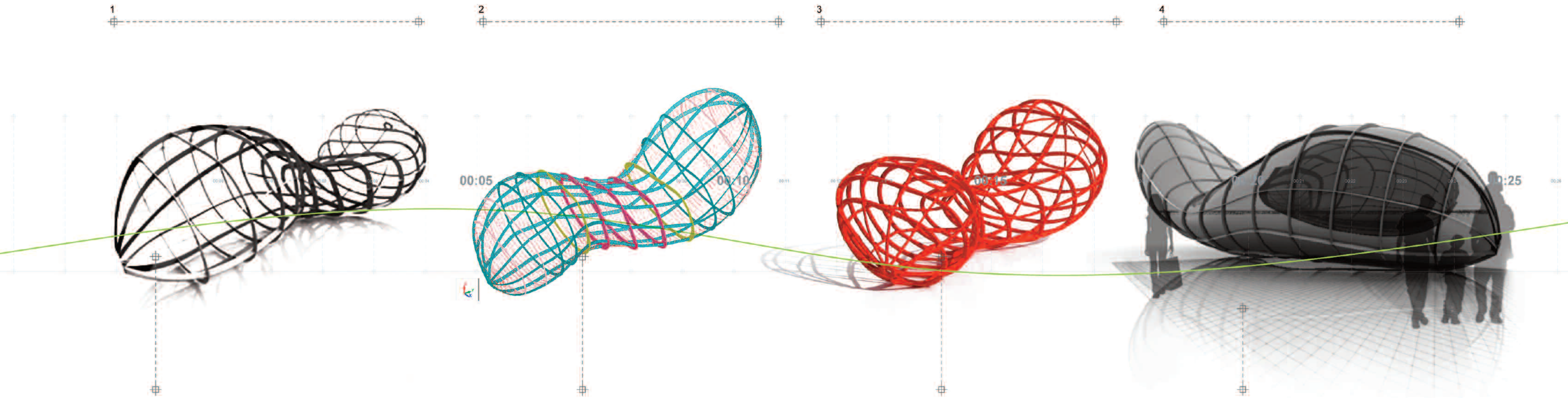
rapid prototyping 2 [2.52]





outcome [3.0]

Two different techniques of prototyping were considered in the manufacture of the structure to achieve the best results; Fused Deposition Modeling (FDM) technique and the Stereolithography Apparatus (SLA) technique.



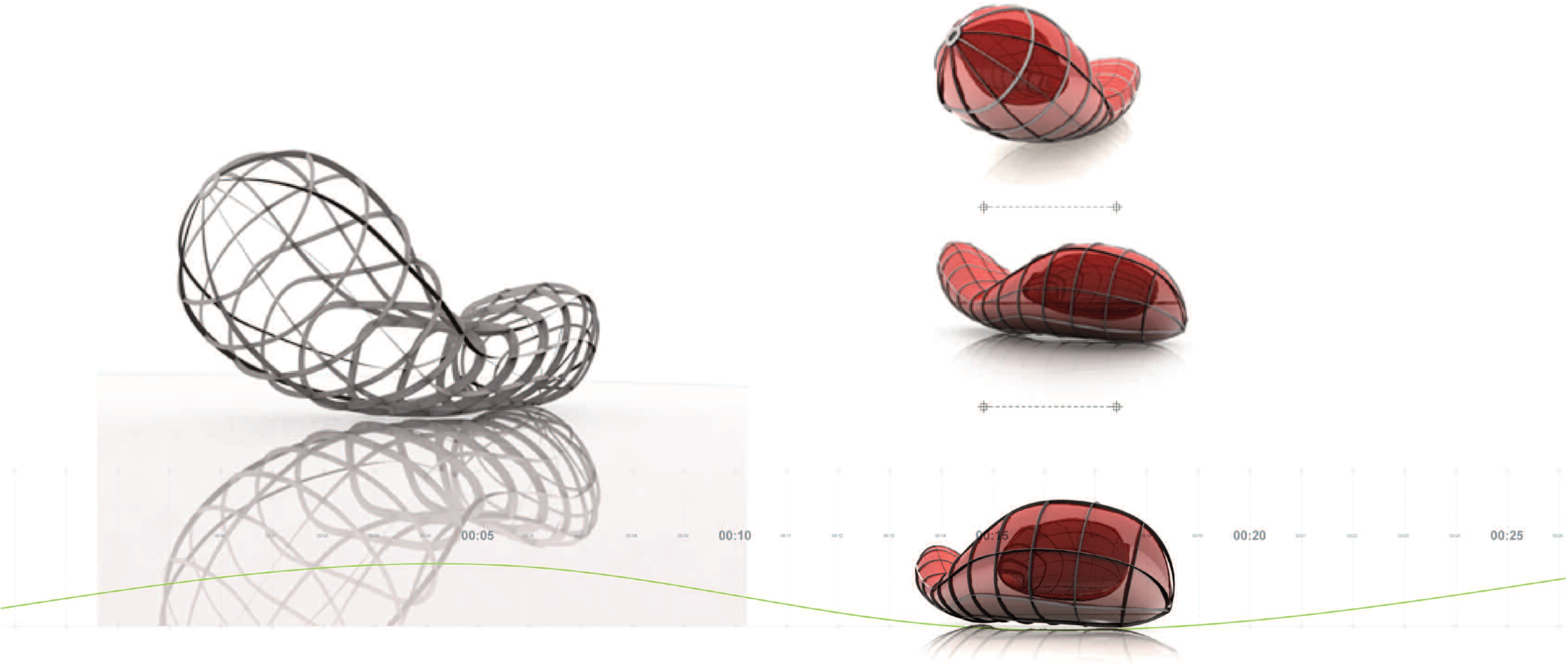
1. Rhino
Rhino facilitates the creation of visual images and walk through of the proposed structure. The image shows the rhino model rendered in 3d Studio Max.

2. FEA Analysis
FEA Analysis allows the structural elements to be sized. Colour coding facilitates the identifying of different thicknesses.

3. Rapid Prototyping
Rapid Prototyping produces a scaled model of the structural form. This physical model can be considered in context in a scaled landscape.

4. Rendering
Rendered collage in landscape.

outcomes [3.1]

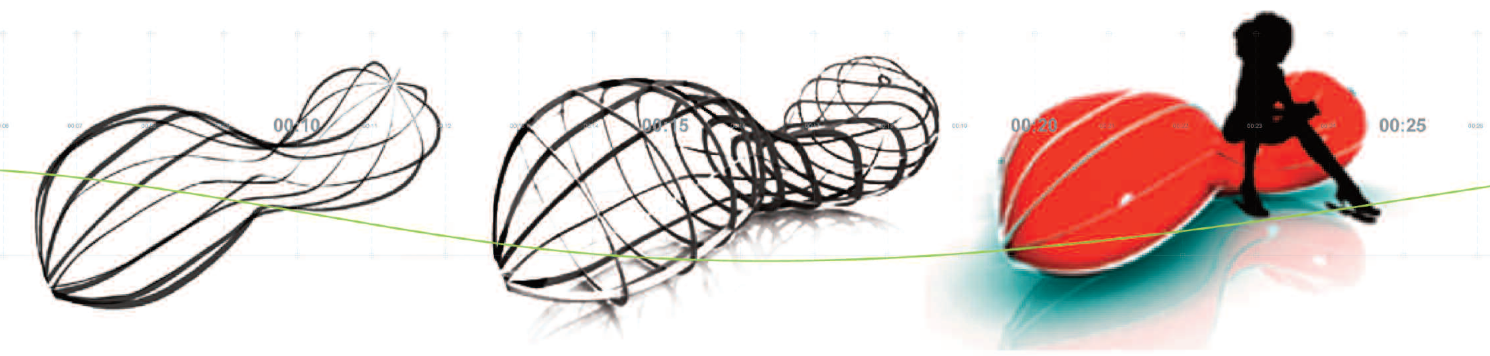


credits [4.0]

Fluid Structures would like to thank the following people for their support and input.

- **Darryl Okey** of the University of Teesside who provided vital help in the scanning and rapid prototyping areas.
- **Dr Judit Kimpian** who corrected the errors in the Rhino model and generally gave great advice and encouragement.
- **Heba Layas**, formally of Fluid, who prepared some of the renders, final visualisations and helped with the preparation of the website.
- **Eric Amoakwa-Boadu** who ran the research aspect of the project on a day to day basis.
- **Simon Garlick** who compiled the information for this web site.
- **Duncan Sweetland** who both constructed the web site and contributed some animations.

We would also like to thank; Kathryn Findlay, Peter, Anne Marie, Mike, Roger, Paul and all the other people at Ushida Findlay Architects who's approach to design was a big influence on us.



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rapid prototyping [2.5]

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