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ABOUT RAMBOLL

Ramboll is a leading engineering, design and consultancy company at the forefront of innovation. From across 200 offices we apply our engineering skills and passion to a wide range of projects around the world.

Ramboll provides consultancy in the areas of Buildings, Transport, Environment and Energy. From this service platform we can draw on skills from each area to deliver the multidisciplinary approach and creative thinking that each client seeks.

The core values of Ramboll reflect a strong commitment towards sustainable development, always seeking to improve the working and living conditions of people with our design solutions.

Combined with our drive for excellence, we are in a strong position to deliver solutions which work for everyone.

Throughout its history Ramboll has received many prestigious awards which recognise the innovative and technical skills of our team.

Ramboll is long established and financially strong, structured for longevity through the Ramboll foundation ownership. Our team of 10,000 dedicated specialists share knowledge globally, applying their expertise and enthusiasm on projects at a local level that benefit both people now and future communities.
In a world where designs and designers are being pushed to their limits, conventional engineering assumptions are no longer enough. With the rapid advance of computational techniques and processing power, it is now possible to explore solutions which could not have been imagined before.

Ramboll Computational Design was set up to harness the power of the computer as a design tool with the aim of developing digital techniques which enable us to challenge traditional typologies and evolve new economic solutions for the built environment.

The inspiration for our work is nature and, in particular, how nature creates efficient solutions which are perfectly adapted to their environments. By writing our own computer code which replicates biological processes, we can start to apply this power to solving engineering problems.

With the application of our in-house code and skills in the interrogation of geometry, we have been able to rationalise complex projects across the world saving time and cost and creating new forms to overcome difficult technical challenges. In this approach the solution emerges from the bottom up and the resulting structural arrangement is one which is completely suited to the forces acting upon it.

Sponsorship of academic research is integral to our development of cutting edge techniques and new approaches to computational design. Our own in-house research has also led to new fields of interest such as digital masterplanning, where technology is being applied to understand and design entire cities.

‘We aim to apply our research into the natural world, mathematics and geometry to creative engineering design, leading to leaner and better performing buildings.’

Stephen Melville, Design Director
Project Description
The Belvedere Sculpture was a collaboration between Loop.pH, a London based design agency and Ramboll Computational Design. The structure was commissioned by Belvedere Vodka for a street concert in New York’s Meatpacking district to promote World Aids Day and was completed within a very tight programme involving design teams based in Bristol, London, Denmark and New York.

The structure consists of 85 carbon fibre rods each 10mm diameter, which are bent to form a 5.2m high arch spanning between two plywood timber bases. Each rod holds a series of LED lighting elements, which together form an image of two trees; the symbol used by Belvedere to advertise their brand. Our challenge was to design a structure which would be stiff enough to withstand the high winds that can be generated in the city whilst maintaining enough flexibility to allow the image of the trees to sway in the breeze. The solution was to use the shape of the arch to create a stiff form as well as tying the rods together using five transparent Perspex ribs forcing them to act as a surface with a combined stiffness greater than that of the individual rods.

We collaborated with Loop.pH on a parametric model using Grasshopper and Kangaroo to create a form generated purely by the bending of the rods. The whole structure was stopped from overturning by steel stage weights inserted into the plywood base.

LOCATION
New York, USA

CLIENT
Loop.pH

ARCHITECT
Loop.pH

VALUE
Confidential

COMPLETION DATE
2012

ENGINEERING SERVICES
Geometry modelling, structural analysis, CFD analysis
COMPLETED BELVEDERE RED SCULPTURE
TRADA PAVILION

Cutting edge research into form finding and surface patterning embodied in a dramatic and sustainable expo structure

Project Description
In late 2011 the Timber Research and Development Association (TRADA) commissioned Ramboll Computational Design to design, analyse, fabricate and construct a pavilion to be a showcase for inventive use of timber and a working trade fair stand for the Timber EXPO 2012. A re-useable thin-shell structure optimised for the often conflicting drivers of structural efficiency, cost of fabrication and ease of erection was created.

A single design team rarely have the opportunity to manage and take responsibility for a project from concept to construction so it was seen as an opportunity to apply and demonstrate the advantages of digital design tools as well as giving reign to our creative skills.

The underlying shape of the structure was designed using an in-house form-finding application to develop structures optimised to resist their self-weight efficiently via in-plane forces. The complex surface created by the software would have been difficult and expensive to replicate exactly so it was “discretised” into planar faces using our bespoke software, to create the 3-valent mesh that used fewer connections than the conventional triangulation of a surface.

The structure used simple hinges to connect adjacent panels. The geometry of the overall form restrains the panels – which allowed the same connection detail to be used throughout the pavilion - drastically reducing costs and manufacturing complexity. The development of the connection detail and production of a parametric model to automate the detailing, positioning of hinges, numbering and nesting was an essential part of the design development of the shell.

LOCATION
Coventry, UK

CLIENT
Trada

ARCHITECT
Ramboll Computational Design

VALUE
Confidential

COMPLETION DATE
2012

ENGINEERING SERVICES
Structural engineering, geometry modelling
TRADA - COMPLETED STRUCTURE
TRADA PAVILION - CONNECTION DETAILS

1. 7NO. M6 S/S HEX NUT
2. 3MM S/S HINCE
3. 15MM BIRCH PLYWOOD WITH 3MM MILLED RECESSES
4. 2NO. M6 S/S COUNTERSUNK BOLTS
Project Description
The KREOD Pavilion is made up of three timber gridshells that implement a number of geometrical optimisation and fabrication algorithms that have not been previously applied to a real structure. The first three pavilions were built in the Greenwich Peninsular site and have been widely publicised. The structure pushed digital fabricators and materials suppliers to new limits and required a highly creative approach to structural design, as well as the application of novel digital modelling techniques.

Pavilion Architecture’s proposal was for a hexagonal mesh generated by applying a ball-packing algorithm to the surface*. From our experience of similar complex three dimensional structures we felt from the outset that the design of the connection would be key to unlocking the efficiency of the structure as a whole.

The connection system must also be adaptable so it can be adjusted for different angles. Although each node has three members entering it, they are not equally spaced. In addition to this, the curvature of the surface varies so the connection must also accommodate the various angles. This factor meant that steel plates would be prohibitively expensive, as each one would have to be bespoke.

To continue the sustainable aspirations of the project and ensure the structure had a lifespan beyond that of most pavilions it was designed to be demountable and be flat packed. This meant glue and screws could not be used to connect the members.

In addition to the above, the architect had a number of other requests to be achieved if possible; as few bespoke components as possible, assembled by a non-skilled work force, economical, aesthetically pleasing with a simplicity reminiscent of a furniture connection.

**[Schiffter et al. 2009]**

**LOCATION**
Greenwich Peninsula, London

**CLIENT**
Pavilion Architecture

**ARCHITECT**
Pavilion Architecture

**VALUE**
Confidential

**COMPLETION DATE**
2012

**ENGINEERING SERVICES**
Geometry modelling, structural analysis
TOP RIGHT: LOAD TESTING OF RECIPROCAL JOINT
KREOD - COMPLETED STRUCTURE
In April 2011, a plywood gridshell sculpture was constructed at the Ramboll lead office in London. Located in the entrance foyer space, the installation was designed to implement and evaluate some of the recent research conducted by the newly launched computational design group.

Firstly, a compression shell was form-found to perfectly fill the confined boundary conditions. This was implemented using an in-house JavaScript that allowed the design team to explore various designs within the constraints in real-time.

Following the form-finding stage a discretisation of the continuous shell along surface curvature lines was undertaken. The conjugate curve networks were found to be almost identical to the membrane stress principal directions allowing for both fabrication benefits and structural performance.

Each member in the shell was a laser cut flat piece of 6mm FSC sourced plywood with no torsional ‘twist’ along its length due to the principal curvature orientation. Plywood was chosen because of its low cost, appearance, sustainability credentials, ease of fabrication and compressive strength under axial load. As the members are also aligned with the principal membrane stresses the self-weight of the structure travels mostly in axial compression to the supports. The density of the member discretisation is kept constant allowing the self-weight to be similar to that of the continuous shell. Due to each member being a constant depth, efficient nesting of the elements on each sheet of plywood was a simple task allowing for minimal material wastage during manufacture. Reference numbers are scorched onto the members to assist with assembly.
LONDON FUNNEL - COMPLETED STRUCTURE
Project Description
In this unique project the client, digital film distributor Arts Alliance, wanted a lightweight, easily transportable venue to house its new performance of ID: Identity of the Soul on a worldwide tour.

The brief required a structure that would meet the technical requirements for video projection and surround sound during live performances, as well as accommodating up to 3,500 people without impeding views of the stage. The structure had to be capable of being erected within two weeks and when demounted it had to fit inside a reasonable number of shipping containers for transportation across the world. It also had to be of the highest architectural quality.

Oslo-based practice, Various Architects proposed a dynamic oval form within an inflatable hexagonal PVC outer skin and drum-like fabric roof. Together with specialist contractor ESS, we developed a structural concept that has met the challenge.

After evaluating a number of different structural options an arrangement of radiating spokes, akin to the wheel of a bicycle, formed by tension cables running between inner and outer steel ring beams supported on steel lattice columns was chosen. The resulting structure is ultra-light, easily transportable and quick to assemble, whilst providing a large, clear space for the theatre area.

The exterior skin is self-supporting and consists of a web of inflatable fabric tubes coated in PVC, with translucent inflatable pillows as infill. To help generate the hexagonal pattern of the pneumatic skin, Generative Components software was used to parametrically control the size and scale of the hexagonal tessellations. The Arts Alliance theatre is believed to be the largest mobile entertainment venue in the world measuring 90m by 40m on plan and in 2008 won the Spark Award.

LOCATION
Worldwide

CLIENT
Arts Alliance

ARCHITECT
Various Architects

VALUE
£3.5m

COMPLETION DATE
2009

ENGINEERING SERVICES
Structural engineering, building services, fire & safety, sustainability
CGI’s courtesy of: Various Architects
Project Description
The new town hall for Tallinn, the capital of Estonia, is a structure composed of 13 intersecting boxes, each of which cantilevers a considerable distance from inset columns at ground floor level. The side walls of each box are blank and therefore provided the opportunity to hide a number of cantilevering trussed frames. The RCD group used the theory of genetic design to evolve an engineering solution that went beyond the traditional structural typology of a truss to deliver a more optimised result.

The genetic algorithm was originally developed by John Holland in the 1960s and is a computer simulation of Darwinian evolution.

The engineers’ genetic algorithm solver initiated a population of possible truss arrangements which were assessed against a performance-related fitness criterion – in this case the deflection of the trussed frame. The resulting solution is one, which could not have been deduced using guesswork or traditional engineering assumptions, and is perfectly adapted to its purpose.

```java
void selection() {
    //Roulette Wheel
    //technique here as described by Melanie Mitchell, 
    //Introduction to Genetic Algorithms p.166
    float myRandom;
    float fitSum;
    for (int i=0; i<newPop.length; i++) {
        myRandom = random(0, totalFitness);
        fitSum = 0;
        for(int j=0; j<currentPop.length; j++) {
            fitSum += currentPop[j].fitness;
            if(fitSum > myRandom) {
                newPop[i] = currentPop[j];
                break;
            }
        }
    }
}
```
Project Description
The new town hall for Tallinn, the capital of Estonia, is a structure composed of 13 intersecting boxes, the largest of which is a 60m tall tower comprising the main council chamber and 37m high lightweight glazed façade. A deep roof structure incorporating a staircase to take visitors to a viewing platform was required and as a result the RCD team developed a tool for finding the most efficient way of fitting structure to the irregular volume of the roof void.

As well as providing support against wind and snow loading, the roof serves to prop the high side walls and huge glazed façade allowing lateral forces to be transferred to the stability core at the rear of the structure.

The tool that was developed used a routine which first releases a specified number of nodes into the volume. Each node is then given a simulated electrical charge so that they repel each other. When the nodes find an equilibrium position they are all an equal distance apart and members are drawn between adjacent points. As such a triangulated structure is derived where all members are of equal length. Engineering judgment was then used to refine the structure in areas of high or low structural density.
ROOF STRUCTURE INTEGRATED INTO THE STRUCTURAL - 3D MODEL
D-POD

Computational analysis optimises uniquely curved form

**Project Description**

D-Pod is a multi-use temporary grid shell structure. The architect’s original design, created using parametric software, required that each member be both curved and twisted. However, elements are often easier to fabricate if they are curved in one direction only. Connection detailing is also easier to standardise and therefore less costly if the curvature occurs only along one plane.

The engineering team created a digital tool to reveal the lines of principal curvature in real time to the designer. The architect was able to assess the curvature network aesthetically before deciding on a final surface form. Applying this curvature network constraint early made it easier to remove the twist effect and simplify connections once the design was finalised.

To make the shape of the grid shell more structurally efficient, the engineers morphed the underlying surface into a new position using a self-written script that integrated with the parametric software. Applying the principal curvature tool from the previous exercise to each new surface ensured the resulting structure was buildable.

**LOCATION**

Worldwide

**ARCHITECT**

Pavillion Architecture

**VALUE**

£100k

**COMPLETION DATE**

2012

**ENGINEERING SERVICES**

Structural engineering
GREENLAND NATIONAL GALLERY

Using digital intelligence to identify lines of principle stress in a structure

Project Description
For the competition-winning design of the new Greenland National Gallery the RCD group developed a reinforced concrete slab solution that looked original and striking while also being more energy efficient than a conventional reinforced concrete flat slab. The engineering design was based on extensive research into mapping stress flows through flat plate structures, using advanced digital tools. The concept uses new research into the actual stress flows through a flat plate structure and also revisits work from the early 1950’s by Pier Luigi Nervi.

Pier Luigi Nervi famously expressed the lines of principle stress in several projects incorporating reinforced concrete floor slabs. When he analysed the stress vector field, he used an intuitive approach based on trial and error.

The team wrote a computer script to map stress flow pathways accurately. By mapping the principle stress vector field of a flat concrete plate with support locations based on the positions of columns in the building frame, we were able to design a precisely calibrated slab where slab thickness varies according to the structural requirement. When the stress flow paths are expressed in reinforced concrete they create elegant, curved, ribbed structures.

LOCATION
Greenland

CLIENT
BIG Architects

ARCHITECT
BIG Architects

VALUE
€8m

COMPLETION DATE
2015

ENGINEERING SERVICES
Structural engineering

GREENLAND NATIONAL GALLERY
3D RENDERS
DETAIL FROM THE DESIGN OF THE GATTI WOOL FACTORY

DIGITAL MAPPING OF A SLAB’S STRESS VECTOR FIELD
An algorithm inspired by electrical behaviour of sub-atomic particles rationalises a complex facade

**Project Description**

The initial scheme for the façade of the new Presential Library envisaged a triangulated diagrid of steel members set out in the form of a Möbius strip. If a traditional rectilinear grid pattern were to be adopted for the setting out of the cladding panels, then every panel and member length would be different making the façade package extremely expensive. The engineers’ challenge was to refine this complex steel façade structure to make it simpler and less costly to construct.

By applying an optimisation routine based on the theory of electrical repulsion engineers were able to refine the design so more panels were the same area and more supporting members were the same length.

The engineers created an algorithmic software script that ascribed to each nodal point in the façade a simulated electrical charge. Following the principle of electric repulsion, the nodes ‘repelled’ each other until they were evenly distributed, thus creating steel members of a standardised length.

A second algorithm was then used to push nodes towards areas of high stress, thus tuning the structure to the forces flowing within it, making it more structurally efficient.

**LOCATION**
Astan, Kazakhstan

**CLIENT**
Kazakhstan Government

**ARCHITECT**
BIG

**VALUE**
£50m

**COMPLETION DATE**
2011

**ENGINEERING SERVICES**
Structural, building services
ALGORITHM AUTOMATICALLY ‘TUNES’ FACADE CONNECTION DISTRIBUTION TO ACHIEVE GREATER STRUCTURAL EFFICIENCY
ARCHITECT’S RENDER
RIGA AIRPORT COMPETITION

Computational analysis of catenaries enhances 3D modelling capability

Project Description
On a competition submission for Riga Airport, the RCD group used computational analysis to model the undulating roof structure which was inspired by the catenary form. In the 19th century Gaudi defined the form of his iconic La Sagrada Familia by making scale physical models using chains with hanging weights - catenaries.

In the case of the Riga Airport roof the form was found using the modern day computational technique of dynamic relaxation – a digital modelling tool ideal for analysing catenaries. The rationale behind Riga airport’s undulating roof surface was that it should dip where there are check-in desks and rise where natural light is needed to channel into the space below. At one end of the building the roof needed to drape down to the floor to create a sense of enclosure.

The initial geometry was created by the architect using some simple structural rules. Our engineers then developed the geometry, maintaining the integrity of the shape but optimising the structural performance significantly using dynamic relaxation. As a result the final design achieved the architects’ vision for an irregular curving roof while optimising the structure.

LOCATION
Riga, Latvia
ARCHITECT
Allianss Arhitektid
ENGINEERING SERVICES
Structural engineering
COMPUTATIONAL DYNAMIC RELAXATION SOFTWARE MADE IT EASY FOR THE ARCHITECT AND ENGINEERS TO MORPH THE ROOF GEOMETRY
OFFICE LOCATIONS

Full contact details for our worldwide offices can be found at www.ramboll.co.uk