Mapping two-way grids onto free-form surfaces

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The advent of free-form 3-D modeling software has allowed architects and designers to create almost any shape imaginable. In order to physically realise these computer models, say as a building or a sculpture, an internal armature can be used along with non-load bearing panels to create the required external surface. Examples include Gehry's Guggenheim Museum in Bilbao and the Body Zone in the Millennium Dome, London . Use of a grid structure, consisting of a lattice of rods (see Figure 1) may be more desirable due to the potential for reductions in material usage and increased internal space. However, it is not always obvious how to create an efficient grid structure on a given architectural surface form.

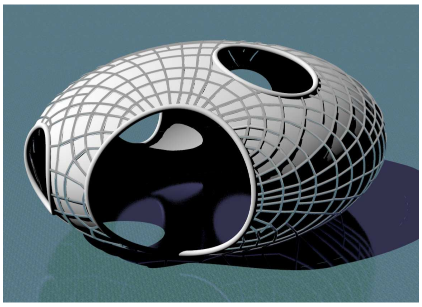


Fig. 1: Principal stress grid on a free-form surface.

A need for development of new computational structural engineering tools applicable to complex geometries has been explained by several authors [1, 2] . Mapping and processing of grid structures with complex geometry are problems frequently encountered by Buro Happold, however existing techniques focus on relatively simple geometrical rules and algorithms to map a grid onto the surface.

This paper will present a novel approach for synthesis of grid structures on free-form surfaces, inspired by recent research in advanced composite structures for aerospace applications [3]. Iterative structural analyses are used to make a more informed selection of the geometry of the grid structure. Central to this proposed approach is the parameterisation of the grid structure in terms of rod angles and spacing which, along with a process of homogenisation, facilitates multiobjective optimisation. The final aim is to create single-layer grid structures with a node connectivity of four, i.e. rods define edges of quadrilaterals, as shown in Figure 1 and often referred to as a 'gridshell'.

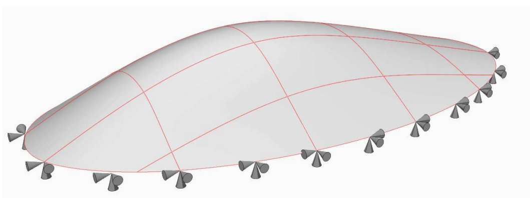


Fig. 2: Example problem: free-form dome with boundary conditions.

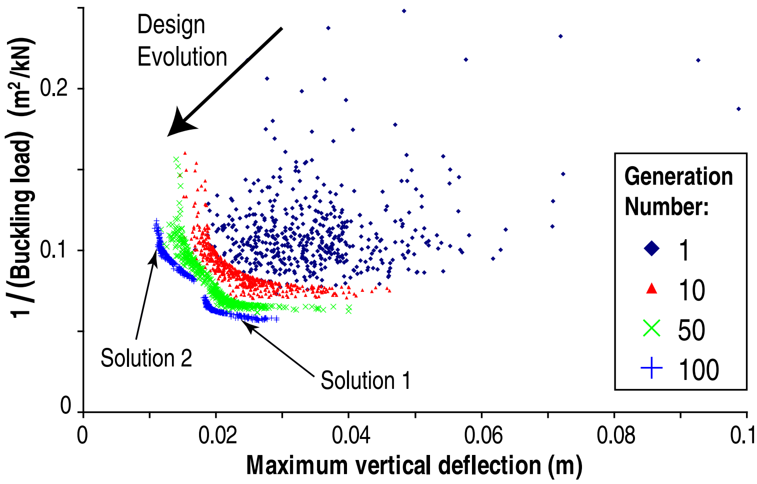
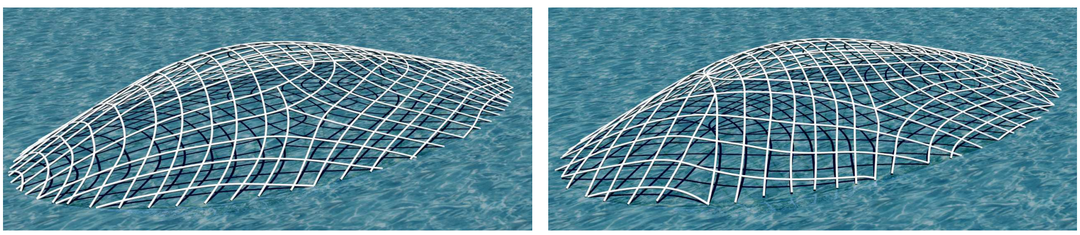


Fig. 3: Example problem: trade-off plot.

An example problem is used to illustrate the proposed method; the surface form is shown in Figure 2. An initial set of grid designs are synthesised on this surface, and are then evolved over a number of generations in order to minimise deflection under snow loading and maximise buckling load (see Figure 3). Two possible final designs from the 100th generation trade-off curve are marked with arrows in Figure 3 and drawn in Figure 4. The first solution deflects 11 mm under the snow loading and buckles under a uniform load of 9.6 kN/m^2, whilst the second solution deflects 26 mm and buckles at 17.5 kN/m^2. Thus each structure has clear performance benefits, and the final choice of design can rest with the project architect and engineer.



(a) Example solution 1

(b) Example solution 2

Fig. 4: Two designs chosen from 100th generation

The example given in this paper shows very promising preliminary results for the proposed design method; the two final designs presented can be inspected visually and both appear as sensible and rational solutions to carry the applied load. Evolving the design through 100 generations gives improvements in the first objective (deflection under snow loading) of approximately 45% and the second objective (buckling load) by approximately 35%. The multi-objective optimisation approach has successfully enabled a set of feasible structures to be created thus, unlike some other optimisation tools, design freedom is not significantly restricted when this new synthesis method is utilised.

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