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Form-finding and structural optimisation of timber gridshell structures

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Introduction

The double-layer timber grid-shell technique, despite being able to achieve large spans with lightweight and stiff construction, has only rarely been used. The reason for the apparent lack of enthusiasm may stem from the unique challenges associated with the design and formation process (Kelly *et al.* [1]) to deform an initial flat grid made of continuous straight laths joined together. To design the Downland grid-shell (Sussex 2001) physical modelling of the structure was a central element of the design process, which was used to determine the boundary condition for the form-finding model (Harris and Kelly, [2]). The final position of the boundary nodes detected from the 1:30 scale model was used as target to the imposed displacement of the boundary nodes of the flat grid. However, the process of form-finding for grid-shells is not straightforward and involves numerous interactions [2]. In fact, as the input parameters for the form-finding simulation come from physical model, a change in the shape requires the making of a new scale model and so on. A method to bypass the need of physical models has been proposed by Kuijvenhoven [3] consisting of a tool which performs, in a first step, the forcing of a general flat grid onto an imposed surface while in a second step, boundary constraint are added and the exceeding grid and external forces (springs jointed between grid and target surface) are deleted so the grid settles again to its final shape. Although this tool represents a novel approach to the problem, it remains as general design method, not usefully applicable for professional practice. In fact only grid-shell with a "continuous" and "plane" boundary curve can be performed, which means that no gates and no spatial boundary curve (like in the Savill grid-shell) can be considered.

Project objectives and goals

The main objectives of the research comprise development of a form-finding and form-improving (structural optimisation) procedure, as well as development of optimal material and connection systems.

The form-finding procedure is pursued by implementing a tool on the basis of previous works [3, 4, 5] which allows determination of the grid-shell geometry by simply assigning an initial reference surface and parameters regarding the grid pattern. Once the grid has been mapped (drawn) on the surface, the correspondent flat silhouette and boundary displacements (form-finding's inputs) will be automatically compiled and inputted to the nonlinear finite element analysis (FEA) which simulate the forming process so, giving as output the grid-shell's final shape.

The subsequent Project's goal is the definition of a form-improving procedure for timber grid-shells. Although the term form-finding has been generally used to define those procedures applied to find the best/optimum structural shape regarding a defined objective (e.g. material minimisation) here we prefer to call those procedures as form-improving in order to highlight the occurring difference between the procedure described above and a method which pursues to optimise one (or more than one) shape parameter.

The third research's objective is the definition of optimal material and connection systems by implementation of numerical and experimental models.

Description of method and results

The form-finding tool is a script implemented by Python programming language. The script presents two main functions:

- Parametric modelling of grid-shells within commercial CAD software. This function allows quick modelling and changes the grid-shell's geometry, avoiding the making of scale models during the concept design phase.
- Elaboration of the geometrical outputs previously found and automatic definition of the FEA model for the nonlinear large displacement simulation of the construction process. Once the 3D grid-shell model has been defined in the CAD software, the script generate the equivalent flat geometry of the grid and corresponding boundary displacements values to perform the simulation in order to find the real shape.

The method for the proposed form-improving (structural optimisation) will make use of genetic algorithms (GA) in order to maximize stiffness/strength performances while minimising the amount of material. The procedure will follow the work of other authors regarding grid-shell optimisation based on GA [6, 7]. However, no investigation of this type has been carried out for grid-shells made of timber. For this reason, the methodological framework will be the same of the previous works, but shape and residual stresses due to the forming construction process will have to be taken into account.

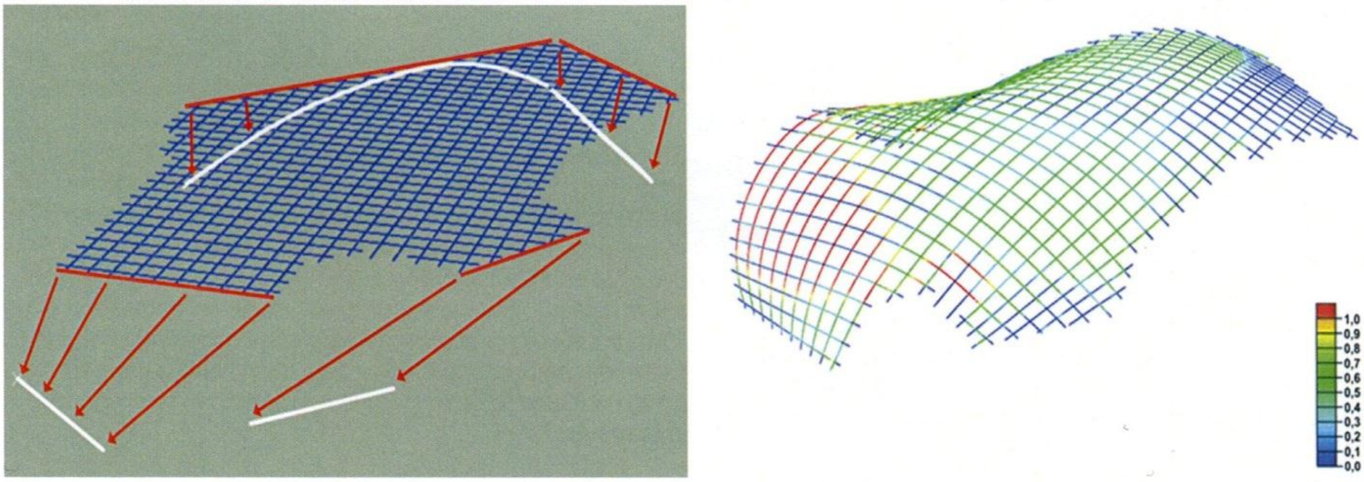

Fig 1: Grid-shell in Lecce, Italy. 2010. Large displacement FE analysis of the formation process.

Potential for application of results

The potential application of the research can be summarised as follow:

- Produce optimal solutions for free-form timber construction systems such as grid-shell structures.
- Provide useful design tools to facilitate design and construction of complex structural systems.

When dealing with timber grid-shells, the required design efforts overcome the advantages in terms of structural performance and material efficiency and sustainability (timber). For this reason, when designing large span roofs, designers often choose more traditional solutions. The creation of supporting tools can increase designer confidence in this type of structures, facilitating the knowledge sharing between concept designer (e.g. architects) and structural engineers.

References

[1] Kelly O.J. Harris R.J.L. Dickson M.G.T. & Rowe J.A. 2001. Construction of the Downland Gridshell. *The Structural Engineer* 79: 25-33.

[2] Harris R.J.L. & Kelly O.J. 2002. The structural engineering of the Downland Gridshell. In: *7th World Conference of Timber Engineering*. Shah Allam.

[3] Kuijvenhoven M. 2012. Particle-Spring Method for form finding grid shell structures consisting of flexible members. *Journal of the International Association for Shell and Spatial Structures*. 171: 31-38.

[4] Toussaint M.H. 2007 A Design Tool for Timber Gridshells. M.Sc. Thesis at Delft University of Technology.

[5] Adrianessens S. Barnes M. R. & Williams C. J. K. 1999. A new analytical and numerical basis for the form-finding and analysis of spline and grid-shell structures. In B. Kumar and B.H. V. Topping (eds.) *Computing developments in civil and structural engineering*. Edinburgh: CIVIL-COMP.

[6] Winslow P. Pellegrino S. Sharma S.B. 2008. Multi-Objective Optimization of Free-Form Grid Structures. *International Conference on Engineering Optimization*. Rio de Janeiro. Brazil.

[7] Dimcic M. 2012. Structural Optimization of Grid Shells based on Genetic Algorithms. PhD Thesis. ITKE. Stuttgart University.

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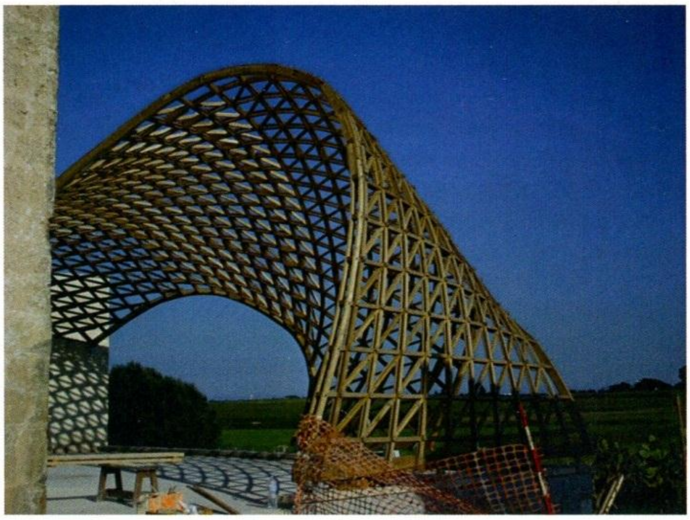

Fig 2: Grid-shell in Lecce, Italy. 2010.