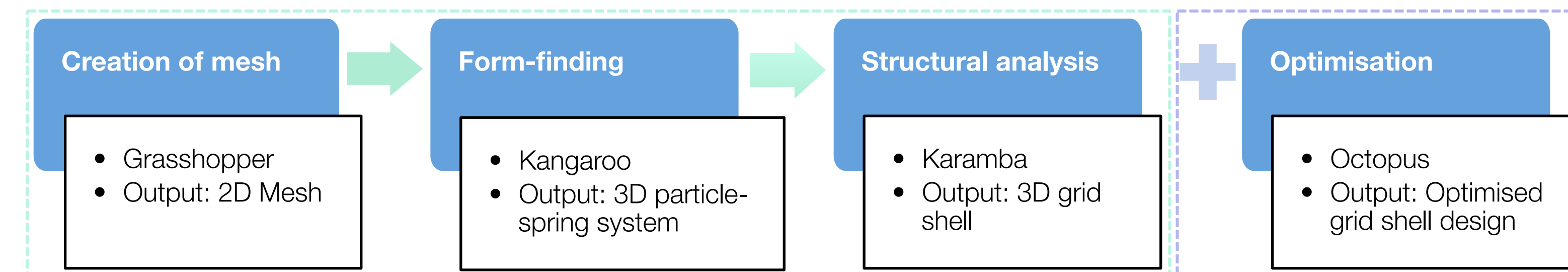


INTRODUCTION

Grid shell structures offer multiple structural and architectural advantages such as optimal use of materials, quick construction process and the possibility to achieve architecturally interesting building forms. Nevertheless, their design is challenging as it involves the use of multiple slender elements. This thesis focuses on the development and testing of a design tool for form-finding and structural verification through optimisation of timber grid shells. The design tool is implemented using the algorithm editor Grasshopper [1].

PROJECT OUTLINE

Part 1: Grid shell design



THE PROJECT

PART 1: GRID SHELL DESIGN

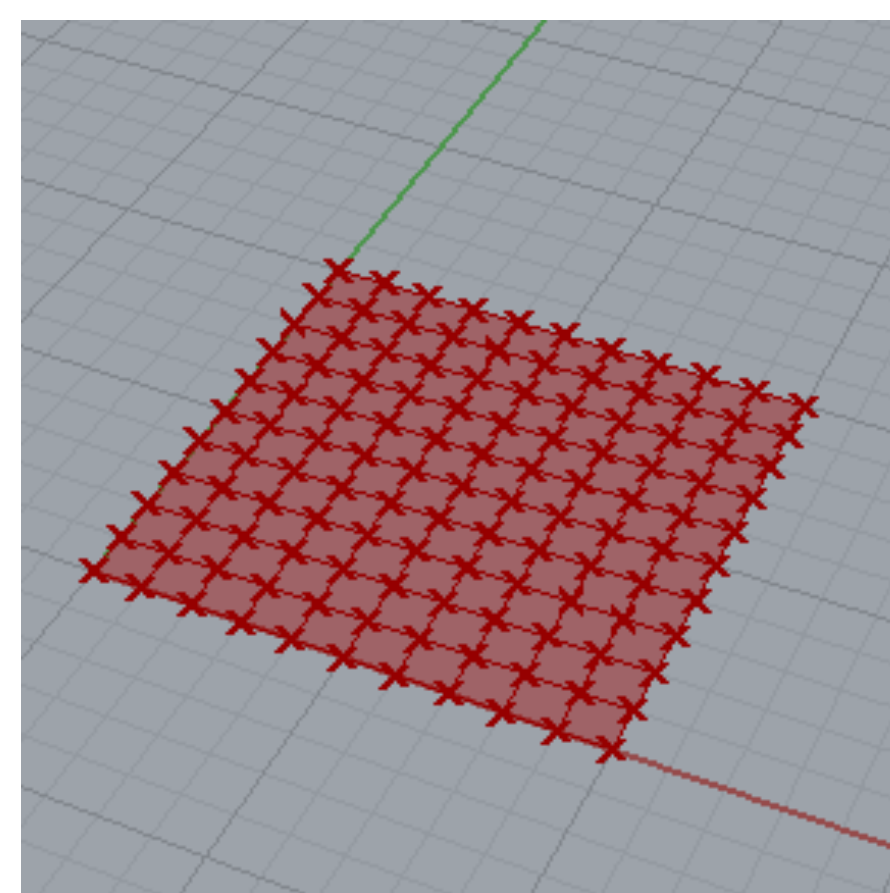


FIGURE 3: 2D MESH

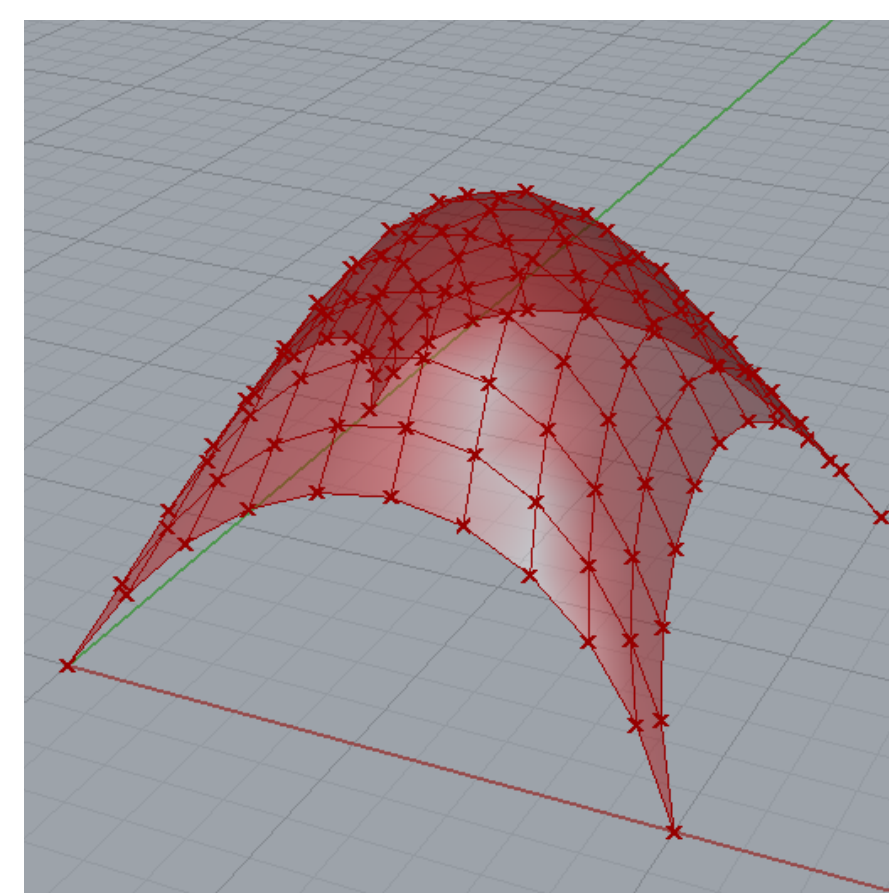


FIGURE 4: 3D PARTICLE-SPRING SYSTEM

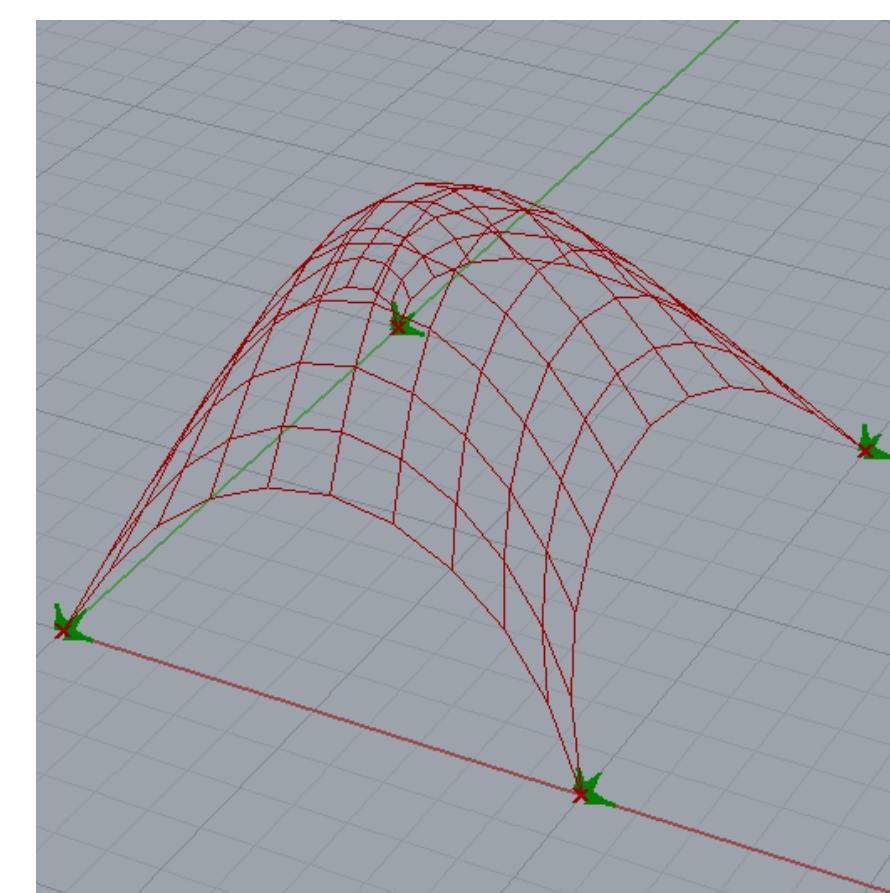


FIGURE 5: 3D GRID SHELL

TABLE 1: 3D GH RESULTS AND % DIFFERENCE WITH OPENSEES RESULTS

	Near supports		Top	
Axial forces (kN/m)	-3.51	-2.5%	-0.05	-8.8%
Shear forces (kN/m ²)	0.05	-	0.05	-
Bending moment (kNm)	0.02	-	0.01	-
Displacement in x,y (mm)	-0.06	-	0.00	-
Displacement in z (mm)	-0.04	-63.7%	-0.09	-3.0%

Grasshopper (GH) is a graphical algorithm editor integrated with the modelling tools of Rhino3D. A timber grid shell is designed parametrically using GH. The grid shell is initially a 10mx10m flat mesh discretised into quadrilateral elements 1mx1m in size (FIGURE 3).

The form-finding process is carried out using the Kangaroo add-on. The mesh is discretised into a particle-spring system, and subsequently the Dynamic Relaxation method is applied to the system. Kangaroo essentially performs a virtual hanging-chain model of the structure in order to find the most efficient shape to carry the applied vertical loads (FIGURE 4).

The particle-spring system is then converted into a real structure and analysed using Karamba, a Finite Element program, fully embedded in the parametric environment of GH (FIGURE 5). TABLE 1 shows that the results from GH are validated using OpenSees [2]. The percentage difference is missing for the shear forces, bending moments and displacements in x- and y- directions. This is because the values are very small in both cases, this is what is expected in terms of grid shell behaviour.

ACKNOWLEDGEMENT

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GRID SHELL STRUCTURES

A grid shell is a **shell** structure discretised by means of a **grid** pattern. It derives its strength from its double curvature.



FIGURE 1: 'GRID SHELL IN THE PARK', SAN ANTONIO, USA

Advantages

- Minimal use of material
- Quick construction process
- Architecturally interesting shapes can be achieved

Disadvantages

- Complex design



FIGURE 2: THE WEALD AND DOWNLAND MUSEUM, SURREY, UK

PART 2: DESIGN OPTIMISATION

The dimensions of the cross-section of the timber laths is optimised to reduce the amount of material used and ensure that bending moments occurring in the grid shell are minimised. This is achieved using the evolutionary solver Octopus, which is an add-on for GH. The results are presented in TABLE 2. The two grid shells are shown on FIGURE 6. The implementation of the optimisation in the grid shell design tool presented in Part 1 is illustrated in FIGURE 7.

TABLE 2: COMPARISON OF INITIAL AND OPTIMISED RESULTS

Section	Initial	Optimised	% Reduction
Volume of material (m ³)	4.33	1.23	72%
Sum of bending moments (kNm)	2.44	0.67	73%
Max. bending moment (kNm)	0.05	0.02	60%

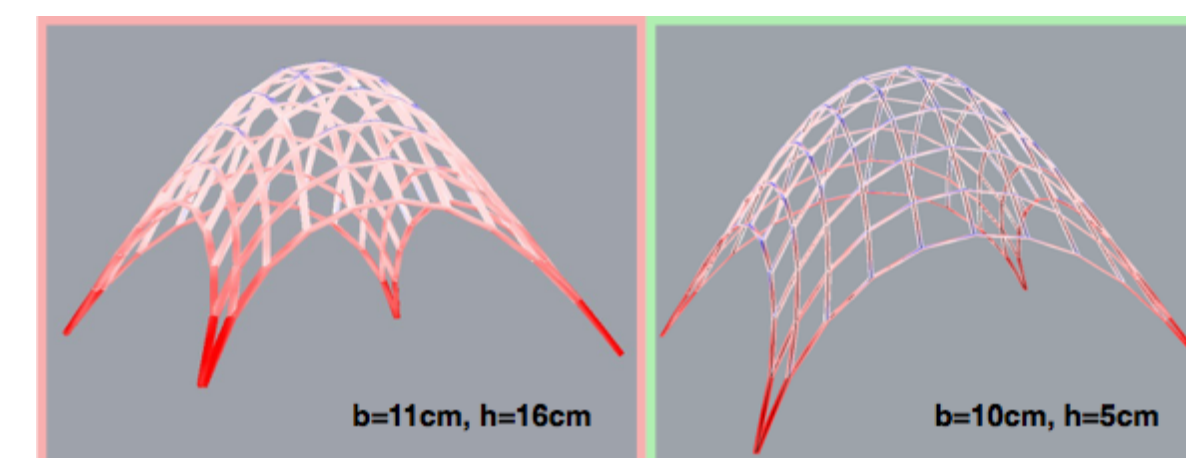


FIGURE 6: INITIAL AND OPTIMISED GRID SHELLS

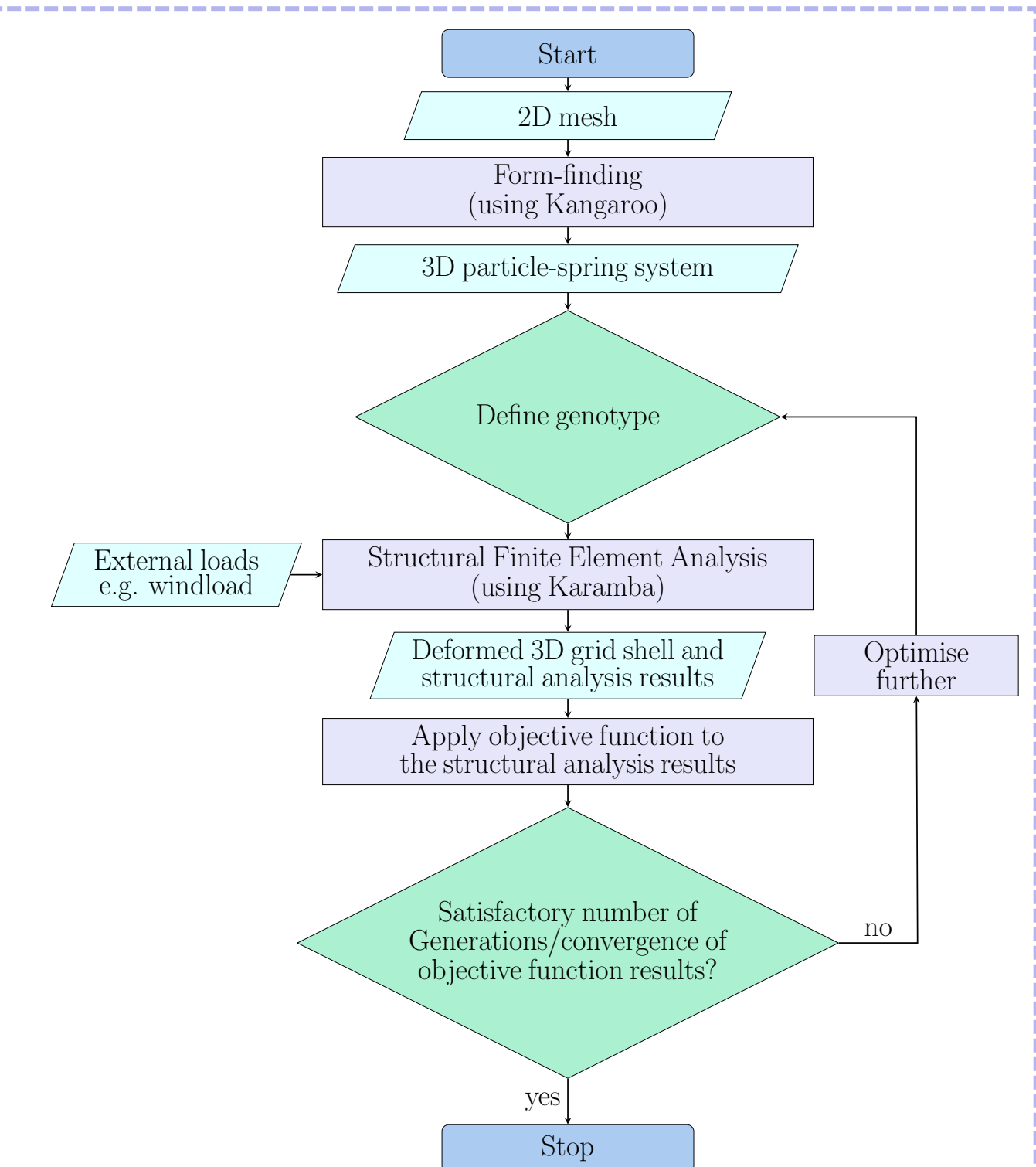


FIGURE 7: TOOL FOR GRID SHELL DESIGN AND OPTIMISATION

CONCLUSION

Form-finding and structural analysis of a timber grid shell can be successfully combined in a Grasshopper model. The analysis results are verified using the finite element framework OpenSees. It is also shown that the parametric environment of Grasshopper allows for an easy parametrisation of the design problem into objective functions, variables and constraints. The inclusion of an evolutionary solver in the Grasshopper model allows for an optimised structural design.

REFERENCES

- Akos, G., & Parsons, R. 2014. Foundations - the grasshopper primer third edition. Available at http://md.uai.cl/workshop/wp-content/uploads/2016_files/Instructors.pdf (Accessed 28 March 2015).
- McKenna, F., Fenves, G. L., Scott, M. H., and Jeremic, B., (2000). Open System for Earthquake Engineering Simulation (OpenSees). Pacific Earthquake Engineering Research Center, University of California, Berkeley, CA.