Design and fabrication of optimised timber trusses with 3D-printed joints

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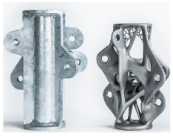
Aims of the research project

To fabricate optimised timber truss geometries and show material weight savings versus traditional truss structures. Although optimised trusses can offer lighter weight and longer spans, their adoption is hindered by a more involved design and fabrication process compared to today's construction methods/tools, particularly at complex joints. We propose to alleviate this by prototyping 3D printed joints, where manual fabrication effort is passed over to an automated high precision process. Moving to digital fabrication of efficient truss structures could help engineers use less material and adopt new/reusable elegant truss forms.

Structural connections current industrial practices


Scottish Parliament Building


(Construction-MX3D, 2020)

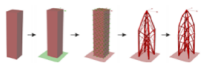

Takanawa joint. (Galjaard, et al., 2015).

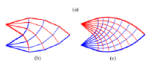

3D Printing, FDM Steel, PLA, ABS

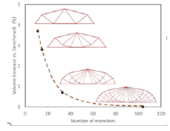
Research- academia practices

$$\sum_{i=1}^{m} q_i^{+} l_i - \sum_{i=1}^{m} q_i^{-} l_i = c$$

Michell Trusses Theory 1964


Grasshopper, Rhino6, Peregrine

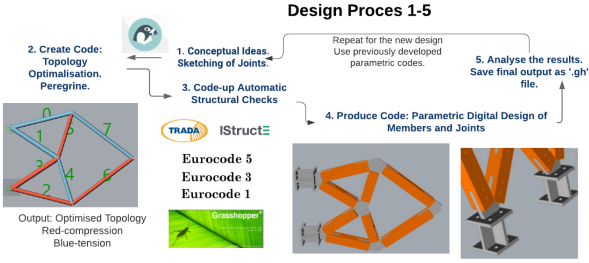

Hemp Trusses


Beam (MBB) Trusses

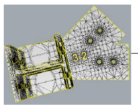
Aim 1: Design optimised 2D trusses using the Peregrine Grasshopper plugin.
Aim 2: Create a parametric truss design to fabrication workflow in Grasshopper.
Aim 3: Manufacture/test the optimised trusses using 3D printing for joints.
Aim 4: Evidence the sustainability and design flexibility of digital workflow.

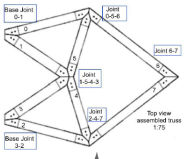
Method

Design Proces 1-5



Manufacturing & Load Testing Proces 6-8





8. Manually Manufacture Members. Miter Saw & Power Tools. Assembly the Final Truss. Load Testing. Hanging Weights.

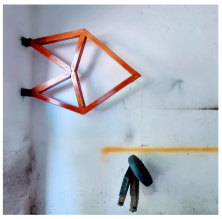

Setting up safe workstation at home garage Marking up the dimensions and angles using drawings.


Cutting timber truss members with Miter Saw.


Drilling holes for bolts.


Doing the slots for knife plate with the Jig Saw.


Finishing off final aesthetics using angle grinder.

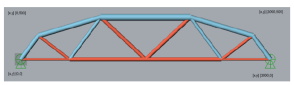

The entire design load (600N) was lifted and released simultaneously. There were no issues with connections, buckling timber elements or truss-wall connection.

Optimisation

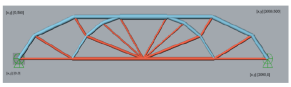
The parametric design and optimisation of the timber trusses applied to different cases, including the simply supported beam below.

Flexibility of Optimisation Tools (Peregrine) Adaptability of Automatic Parametric Designs. All in one software.

Design domain. Simply-supported beam truss with point middle load.


Truss 1 via layout optimisation, 9 divisions. Blue- tension. Red-compression.

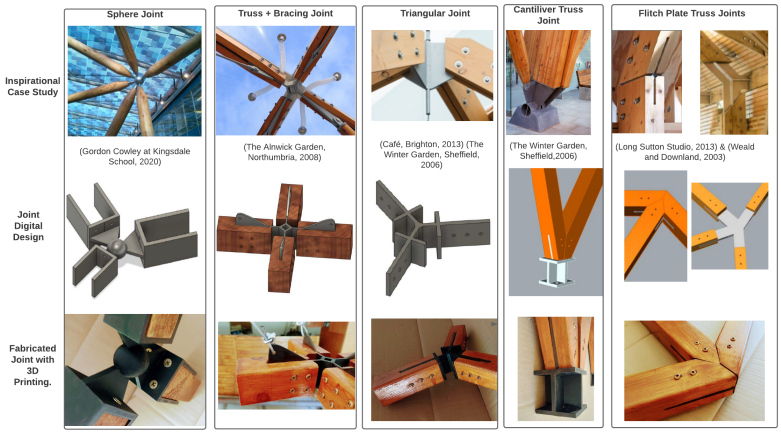

Truss 1 parametric design. C16 timber members with steel flitch plate connections. 30% bigger volume than Truss 2.


Truss 2 via layout optimisation, 21 divisions.


Truss 2 parametric design (the same code as per Truss 1), C16 timber members with steel flitch plate connections.

Joints

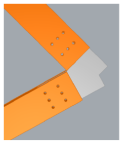
Digital manufacturing for complex and flexible connections

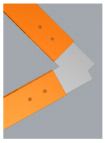


Parametric code for joint design and sustainability.

Options for the bolt connection:

Combinations generated depending on user input (member thickness and loads). All generated based on EC 3 & 5 automatically in GhPython.


3 rows of bolts
2 bolts


1 row of bolts
2 bolts

Sustainability assessment:

GhPython code included automatic calculation of Embodied Carbon. Designs could have been easily compared.