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Computational Form-Fitting with Non-Standard Structural Elements

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Abstract

Some naturally-occurring materials, such as timber and stone, have inherent structural capacity without the need for costly and energy-intensive processing. However, in their original forms as trees or irregular rubble, these materials are considered useless for structures, primarily because their shapes and material properties are too diverse for conventional structural design methods. This paper introduces an approach for designing viable structural geometries using geometrically and mechanically diverse structural elements. This work focuses on design processes for structures using minimally processed round timbers which are of too small a diameter or are too swept or crooked to be valuable for sawn timber production. The proposed approach could make it easier for engineers and architects to design using low embodied-energy materials such as round timber.

Keywords: Computational design; form-finding; timber; optimization; non-standard elements.

1 Introduction

In conventional structural design, trees and stone are typically broken down into their constituent parts (fibre / sawn timbers and aggregate / blocks) before being used in structures. This allows designers to consider these products as effectively infinite supplies of identical elements. To use these materials in their whole, unprocessed form, however, designers must be able to make use of *finite* sets of *diverse* elements. (Fig. 1)

2 Precedents:

Existing literature has addressed this problem using automated computational tools which help designers find and optimize structural solutions [1][2][3]. The strategies used can be grouped into *1) Growth, 2) Attraction, and 3) Fitting* methods. Growth methods ensure connectivity between elements by adding elements to one another sequentially, often following "target" points, curves, or surfaces. Attraction methods relax the connectivity constraint initially by first placing elements onto target geometry, and then "attracting" these elements together until connectivity is achieved.

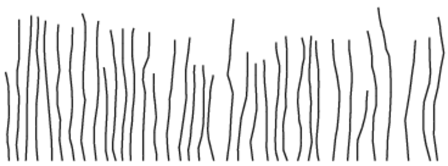

Figure 1. A "Library" of non-standard round timbers represented as "skeletons" with diameter.

Fitting methods allow the designer to pre-define a viable structural layout consisting of "virtual elements" (Fig. 2). Non-standard elements are then chosen based on whether they have sufficient resistance to replace the virtual elements in this structure, and if so, are "fitted" into that location. The major advantage of fitting methods is that they help ensure that the discovered structure satisfies structural constraints. Fitting methods, however, restrict the range of possible solutions to those which closely match the initial predefined topology.

3 Proposed Method

3.1 Structural Checks at Each Step

An existing implementation of the fitting method uses a pre-calculated "resistance" value to select elements, but only performs overall structural analysis after all elements have been placed [2]. In the proposed method, the full structure is analysed as each new element is placed, ensuring that the entire structure meets ultimate and serviceability limit state checks at all times.

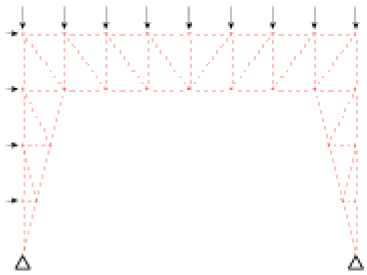

Figure 2. A user-defined input structure consisting of "virtual elements".

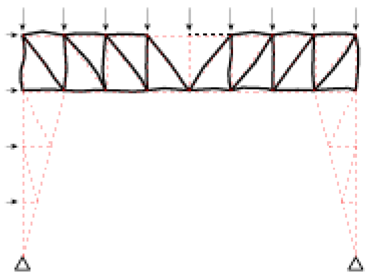

Figure 3. Input structure partially replaced by whole-timber elements.

This helps designers to find viable solutions faster by avoiding time-consuming redesign later in the form-fitting process.

3.2 Hybrid Standard/Non-Standard Structures

Existing methods do not address cases where no non-standard element can be found to safely replace a virtual element. In the proposed method, unfitted virtual elements can be sized as conventional standard elements. This allowance for hybrid designs using both standard and non-standard elements increases the number of buildable solutions, at the cost of increasing the use of high embodied-energy standardised elements (Fig. 3).

4 Conclusions

This research demonstrates a design approach for structures using minimally processed non-standard elements which improves the speed at which designers can find viable structures, and the increases the number of buildable solutions which are likely to be discovered. Further work will address design using forked timbers and structural optimisation of designs discovered, particularly with respect to buckling.

5 References

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