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THE POTATOES SAGA: MATERIALIZING DISCRETE STRUCTURES USING HYBRID FABRICATION TECHNIQUES

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ABSTRACT

With the advent of additive manufacturing techniques, the possibilities for designing and fabricating real-scale structures beyond the ‘conventional’ ones have grown exponentially in the last years. On the one hand, we have structures that are conceived and built as monolithic systems, i.e. the structural elements are merged into a continuum configuration, so that the division among the elements is not possible. The advantage of digital fabrication for continuum typologies is that complex non-standard shapes can be built as long as they can be 3D printed, e.g. by layer deposition techniques. This advantage is thus limited by the sizes of the pieces which 3D printers are actually able to produce. On the other hand, we have discrete structures that are conceived and built as a system composed of several parts, i.e. the structural elements are separate entities and therefore they can be fabricated independently and be assembled *a posteriori*. In the experiences described in this paper, a hybrid approach, using standard 3D printers, was proposed to explore to which extent large-scale discrete structures can be conceived and fabricated by assembling timber battens connected by 3D printed nodes. The conception of those nodes, so-called potatoes, became the keystone stage of a process in which design and fabrication are interlinked under the influence of the structural typology, the inherent PLA and PETG’s material properties, the 3D printing settings, and the lessons-learned from the assembly process.

WHITE POTATOES

The earliest versions of these nodes were devised by a group of graduate students at *Universidad Catolica del Norte* (UCN, Chile), during a workshop aiming at the design and construction of a shading artifact

(Fig.1a). This gridshell structure was composed of 48 timber battens of 20x50 mm section, arranged in a Voronoi pattern and connected with 28 3D printed PLA+ nodes, which included plates to be inserted in the timber battens (Fig.1b). Within the tight schedule, most of the attention was paid to the design of the nodes, which were planned to be topology optimized following the studies of Prayudhi [1]. However, the first 20% infilled nodes took an average of 20 hours to be printed, prompting the team to speed up the process by dropping the topology optimization in Grasshopper, as this procedure was also time-consuming (Fig.1c). An additional problem was that some nodes were connecting up to five bars, thus, to give enough space for the connecting plates and avoid bars' overlapping, students tended to design massive nodes, resembling organic forms, which were quickly named as potatoes (Fig.1d). Finally, although the plate-connection proved to be easy-to-assembled, their inherent lack of out-of-plane stiffness combined with the use of relatively long bars (~2m), led to 3D printed nodes breaking under small deformations of the structure and thus, to an overall instability of the gridshell structure.

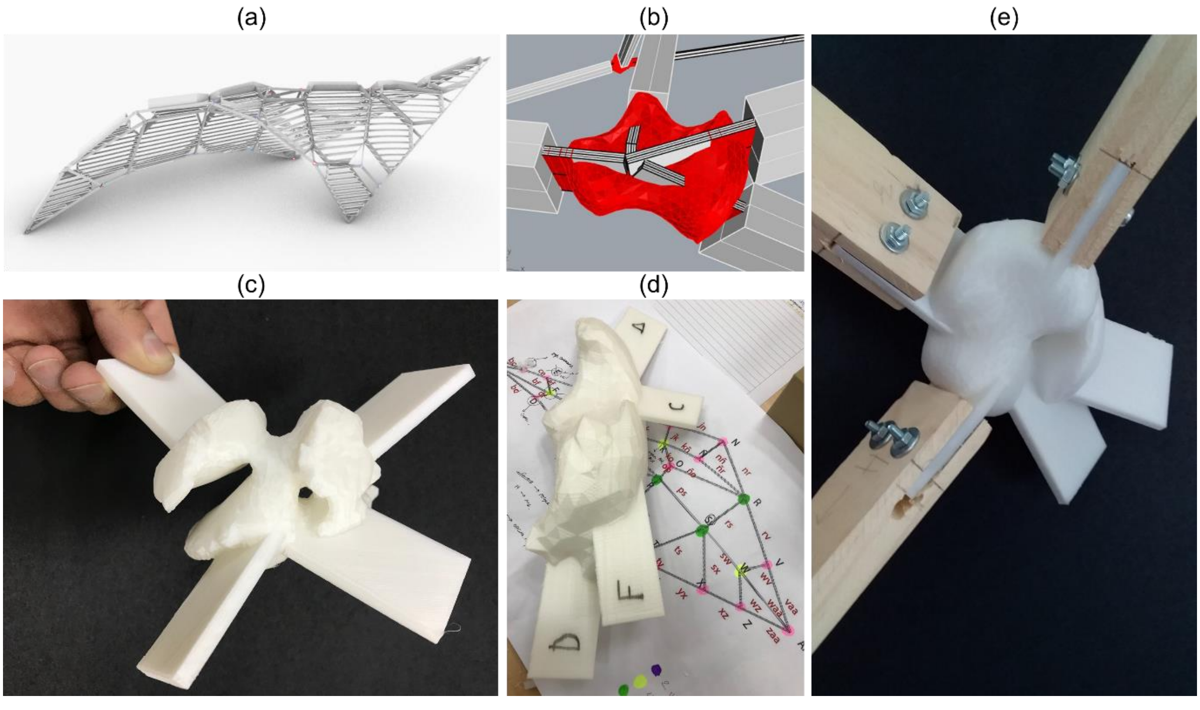

Fig. 1. (a) Digital model of the shading artifact; (b) example of a 4-bar node design; (c) a topology optimized node; (d) the first potato; and, (e) a node with timber battens.

ORANGE POTATOES

The second attempt to build a freeform gridshell structure took place in Yasar University (YU, Turkey), where architecture graduate students designed *the Gate* [2]. Although this structure had a similar footprint area to the shading artifact (~6m^2), it consisted of a larger number of timber battens: 129 bars of 22x44 mm section connected by 68 PLA+ nodes

(Fig.2a), which increased the structure's stability and torsional resistance. Given the number of concurrent bars reaching each node (Fig.2b), these were designed with connecting boxes where the timber battens would be later inserted (Fig.2c). Students were free to design the nodes, however they were requested to apply a design strategy that could reduce printing time, for example by inserting holes in the nodes (Fig.2d). With the same purpose, the infill percentage was reduced from 20 to 10 and an 0.8 mm nozzle was used, instead of the default 0.4 mm. Although these strategies indeed decreased the printing time, the strength capacity of some nodes was compromised (Fig.2e), and thus, they had to be reprinted with 20% infill and in a different printing orientation. In terms of connection, the box-based system proved to be stiffer than the plates, however it added a practical assembling problem, as some bars did not fit in the nodes.

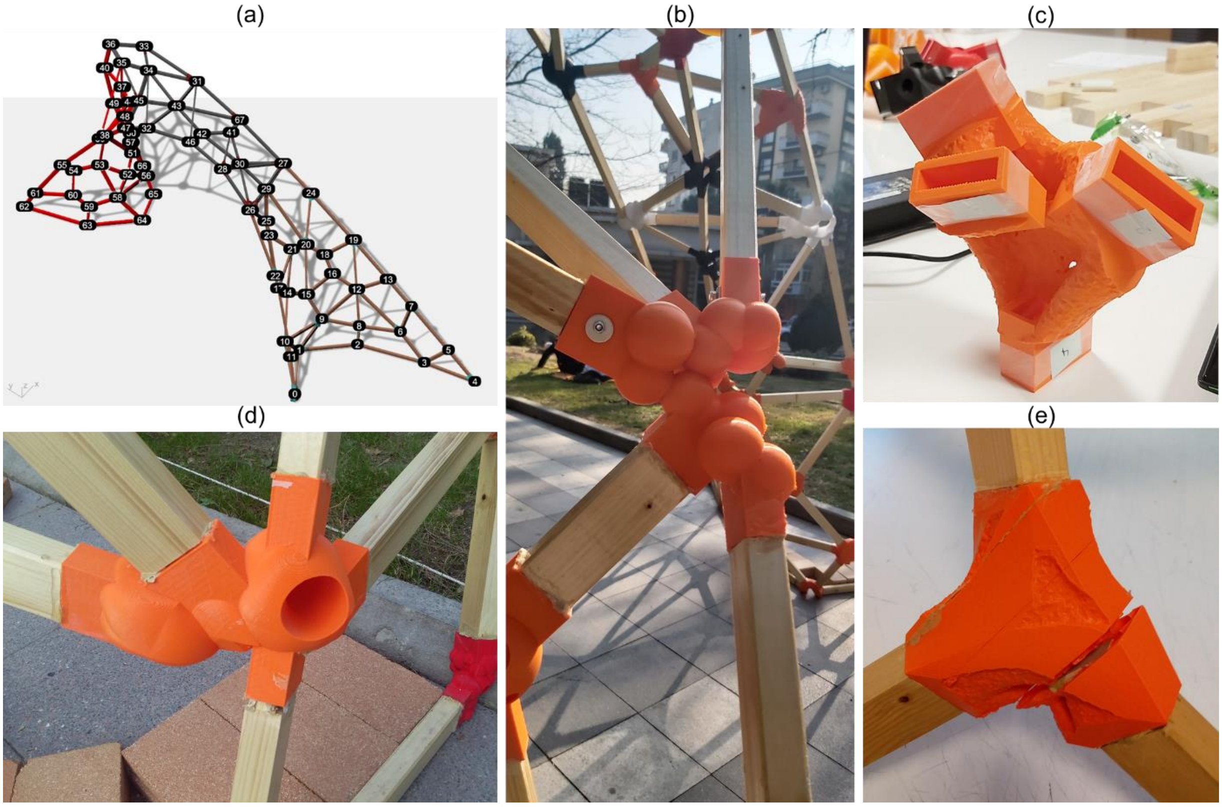

Fig. 2. (a) Digital model of *the Gate*; (b) example of a 5-bar node design; (c) the connecting boxes; (d) example of a potato with a hole; and, (e) a broken node.

SPROUTED POTATOES

Hybrid fabrication techniques were further applied in the design and construction of a topology optimized cantilever prototype [3]. Given the optimized nature of this 1.80 x 0.60 x 0.28 m structure, it only consisted of 19 timber battens of varied cross sections, connected by 10 PETG nodes (Fig.3a). To overcome the challenge of connecting regular section bars with organic-shaped nodes, each node features several two-piece connecting boxes. One of these pieces was glued and screwed to the concurrent timber bar, and the other was merged into the 3D printed node, including stiffeners at each corner (Fig.3b). This separation facilitated the assembly process as these two parts could be now connected using 4 mm bolts (Fig.3c), in number of six or eight for attaching rectangular section bars (Fig.3d), or only four for squared section bars (Fig.3e).

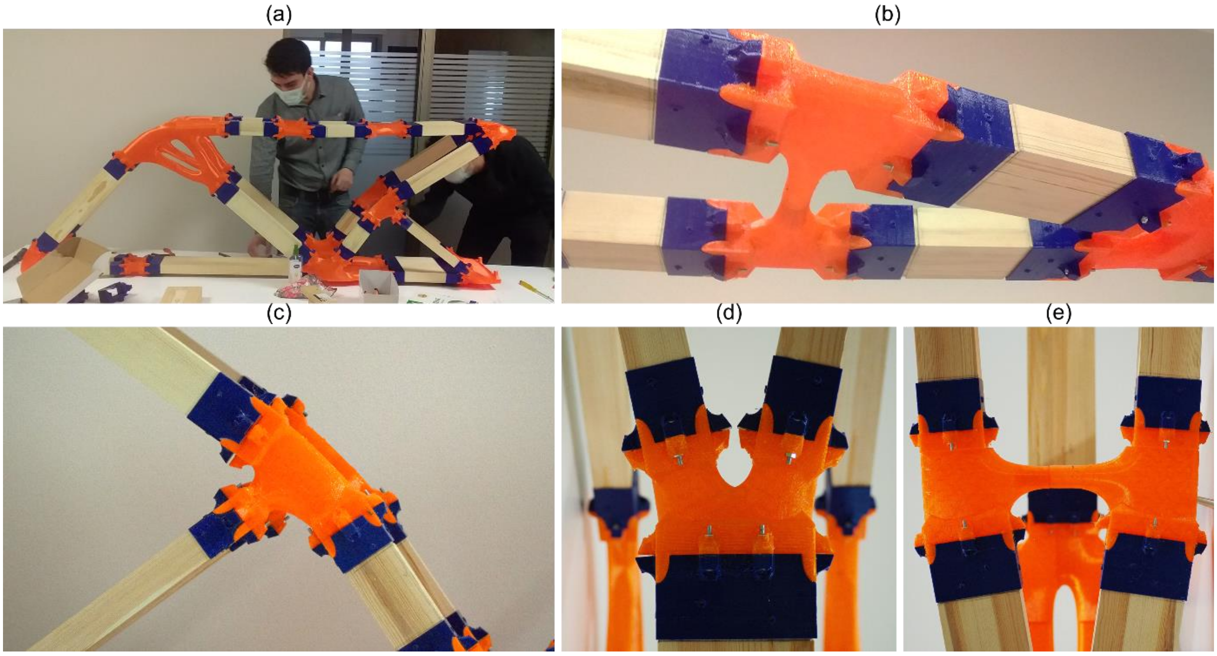

Fig. 3. (a) Full scale model of the cantilever; (b) example of a 4-bar two-piece node; (c) a node connecting bars; (d) a 4-4-6 node; and, (e) a 4-4-4-4 node.

CONCLUDING REMARKS

Based on these experiences, in which design and fabrication processes are interdependent, it can be concluded that design of the nodes is the key step to reduce printing time and material demand; printing time is the most important factor to consider when planning. While printing parameters such as infill %, type of filament, and printing orientation influence the mechanical strength of the nodes, further research is needed to determine the optimal material design of nodes within specific structural typologies.

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