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2021 nTopEd Challenge

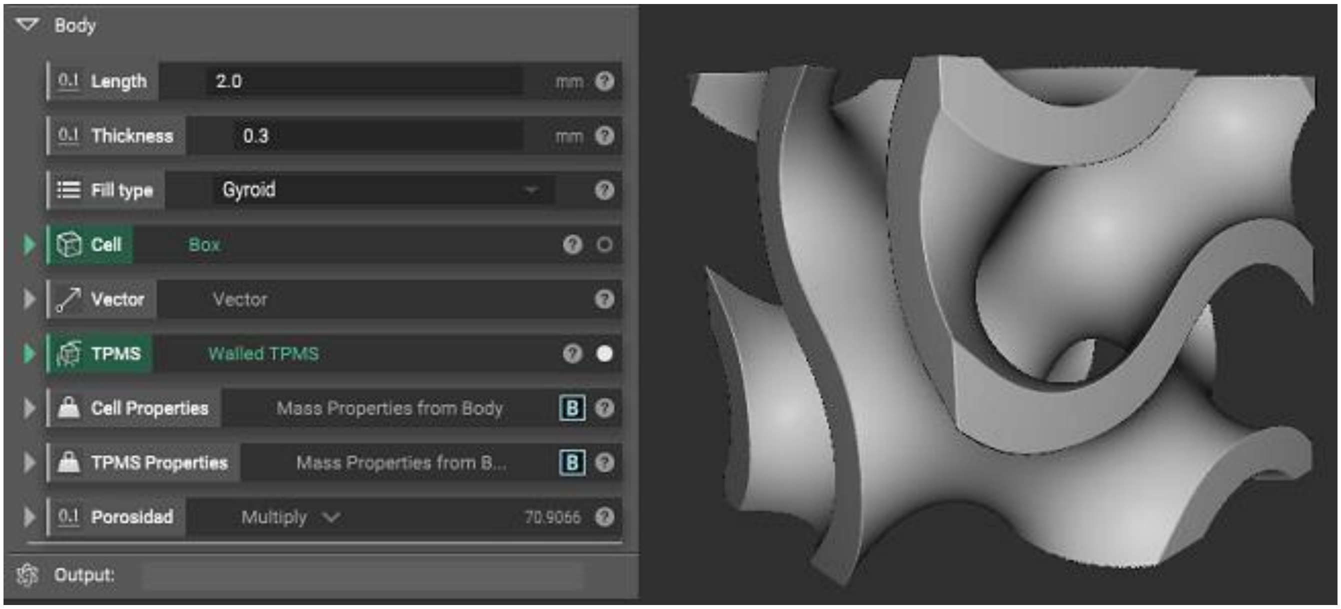
Design of the Internal Structure of a Cranial Implant with graded TPMS Lattice Structures

In Colombia, the statistics of patients suffering Cranioencephalic traumatism (CET) are highly worrying, especially as a consequence of traffic accidents. In fact, in the country there are 200 cases of CET for every one hundred thousand inhabitants, of these 70% manage to recover. The National Institute of Legal Medicine and Forensic Sciences indicates that multiple trauma (including CET) was recorded as 65.5% of fatal injuries in traffic accidents, followed by CET, with 27.2%. This is one of the main causes of death and permanent disability, which is why it is considered a public health problem [1].

As a case study, we used the nTop Platform to design a new cranial implant from the CT reconstruction of a 33-year-old man who suffered a motorcycle accident in 2012 in Bogotá, Colombia. Consequently, he presented a concussion, increased intracranial pressure, and fractures in the left parietal bone. The treatment consisted of the fractured section's excision to reduce intracranial pressure and subsequent replacement with a conventional implant, which dislocated from its original position a few days after implantation. We proposed to mimic the real cranial bone's porosity profile with a graded TPMS lattice structure that could promote osteointegration and fixation to existing tissue.

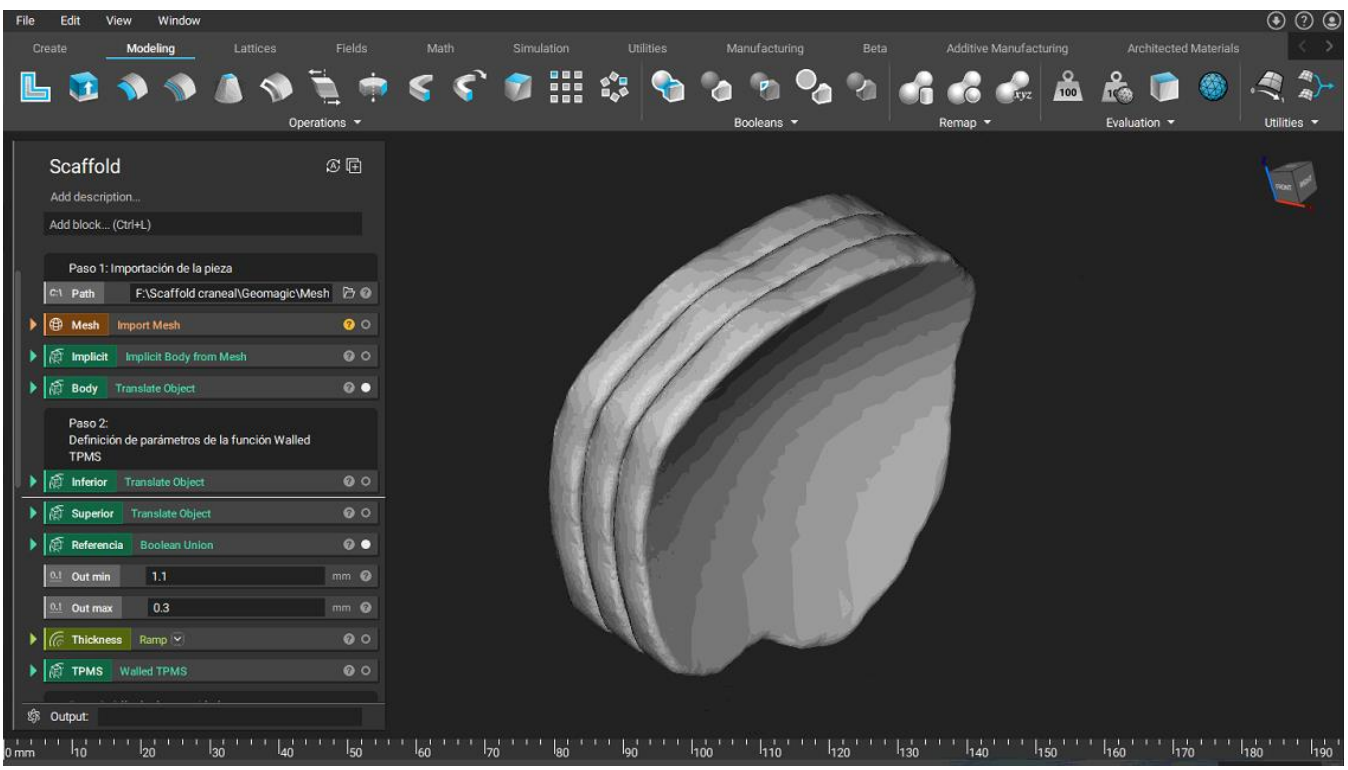
Two main critical biological processes are affected by pore size: the initial cellular colonization of osteoblasts and pre-bone tissue vascularization [2]. Large pore sizes allow adequate vascularization, while small pore sizes allow good colonization. An approximate range of pore size between 300µm and 600µm equilibrates both processes [3]. The transverse profile of the cranial bone has a sandwich structure with three layers. The outer and inner layers are cortical bone, which is relatively dense and strong, and the middle layer is trabecular bone, that is, porous bone, also called diploë. [4]. As a function of depth from the internal to the external surface, a bone porosity profile shows that the transition from cortical bone to diploë occurs when bone porosity is 30%. Also, the maximum porosity at the diploë is 80%.

In bone implant applications, TPMS structures have some advantages over other structures, for example, a single cell domain with improved pore connectivity and smoother wall curvature compared to truss-based structures, which is associated with better bone growth. Among the different TPMS types, we selected Gyroid due to its manufacturing precision, high interconnectivity, and permeability. According to the requirements, the pore size value is 650 µm and the porosity value is 70% in the critical central section, i.e., a solid fraction of 30%, and the unit cell size is 2mm [5]. We created a workflow to calculate the gyroid unit cell's porosity as a function of its thickness. We found that a cell thickness of 0.3 mm produces a porosity of 70.9%.



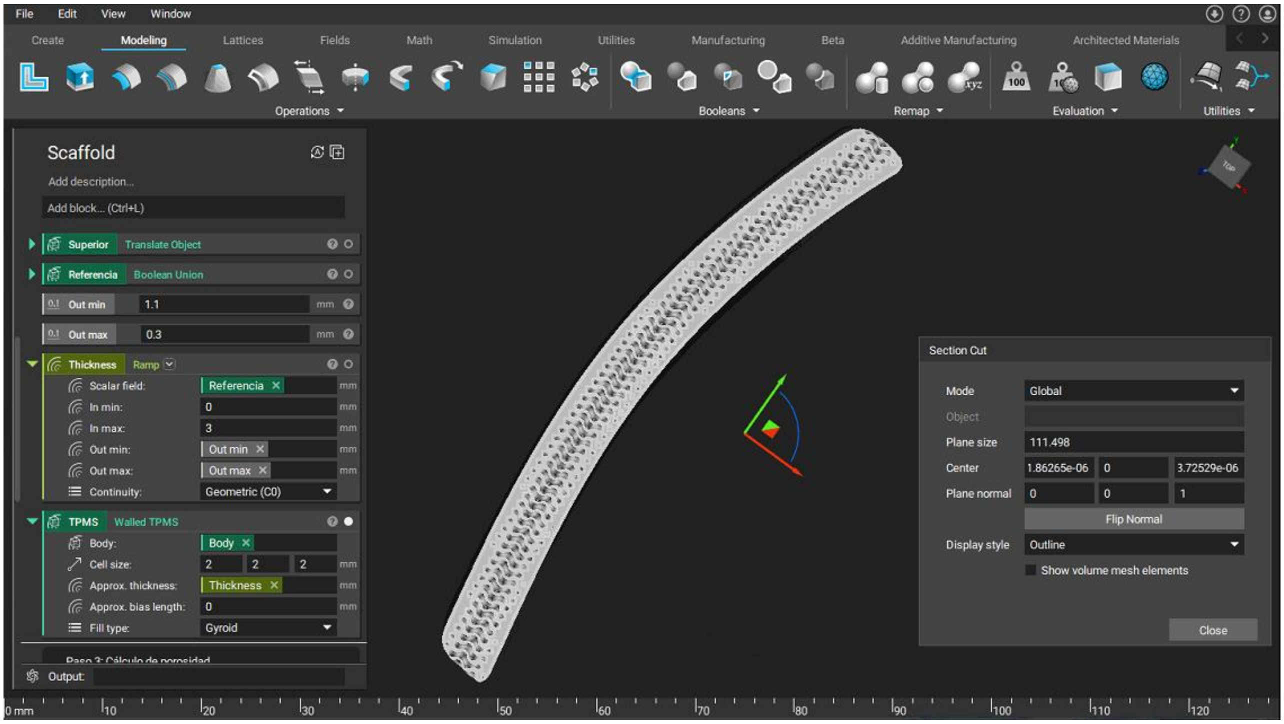
nTop workflow for calculating the unit cell's porosity

The ramp function allows for varying the wall thickness depending on the depth of the implant cross-section. Therefore, the input range is the depth value, and considering the outer faces as the reference scalar field, it varies from the outside at 0 mm to the middle section at 3 mm. The output range is the wall thickness value, which varies from 1.1 mm with low porosity on the outside to 0.3 mm, the value determined in the middle section. To specify the exterior faces as the scalar reference field, we locate two bodies at the edge of the geometry, one on the upper face and one on the lower face, and later joined using the BooleanUnion block.



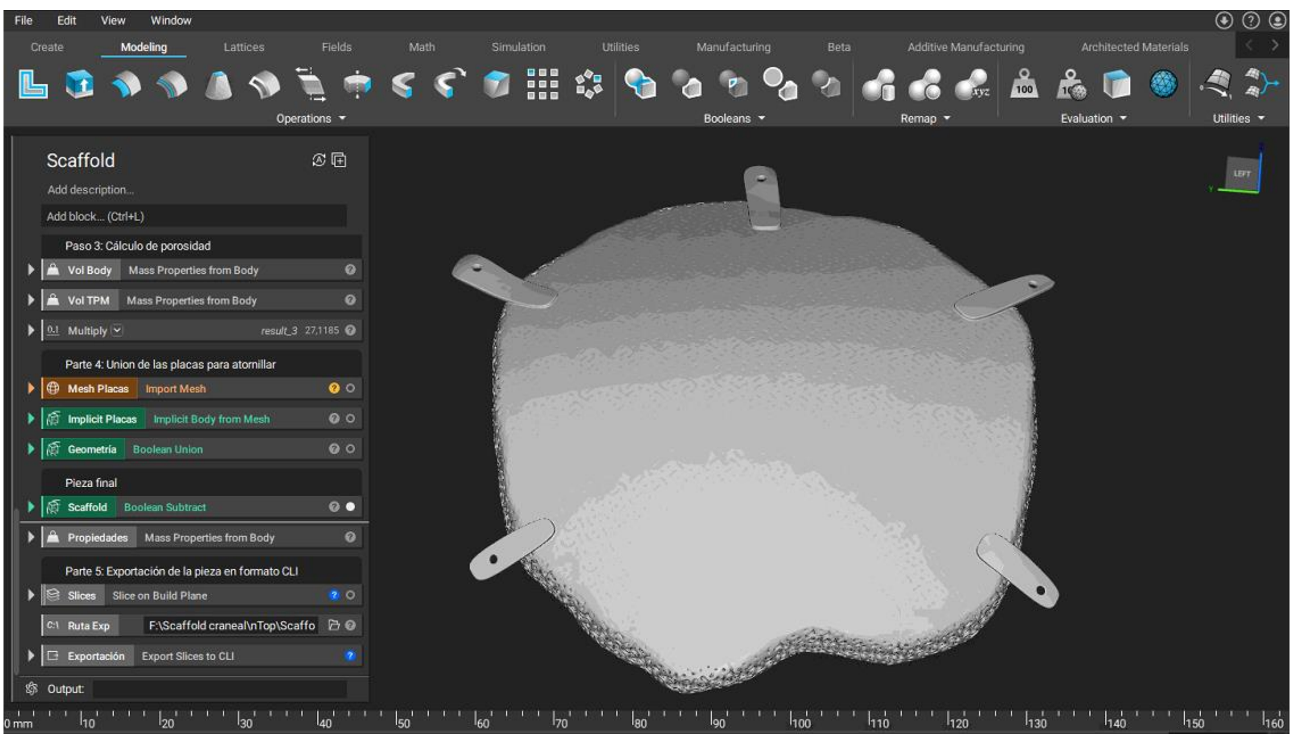
Reference scalar field body

The following figure shows the Walled TPMS function's final parameters and the section's result with the porosity distribution. The scaffold's final microstructural design meets the design requirements and is similar to the structure of real bone.



Microstructural design of the scaffold

Finally, the fixing plates' CAD model is imported and joined to the implant to complete the final design. The diameter of the screw holes is 1.1 mm, according to the screw catalog [6].



Final design of the scaffold

Resembling natural bone is one of the main challenges for designing synthetic bone replacement implants. Bone macrostructure has a functionally graded porosity, but many bone-implant designs have lattices with constant or multi-layer porosity.The workflow developed can be applied to other bone implants according to the specified input parameters and the required geometry. Therefore, the relevance of this work is to resemble the bone's internal porosity using graded TPMS lattice structures to apply in the design of cranial implants, but also in other kind of bone implants, that could better mimic the tissue improving the implant's biological and mechanical properties and promoting bone regeneration in synthetic bone replacement.

References

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